
Gold Mining and Acute Respiratory Infection in Children: A Retrospective Cohort Study in Vatukoula, Fiji.

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Degree of Master of Health Sciences
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Dedication

I dedicate this piece of work to my loving and hardworking mother, late Mrs Ruci Tinai, a mother that sacrificed her life to prepare my future; dearly missed but will always be remembered.

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Summary

Air pollution exposure contributed to an alarming death toll of 7 million people yearly, making it the world's most significant single environmental health risk. Gold mining emission consists of some of the most harmful and toxic air pollutants. However, studies on the effect of gold mining air pollution on respiratory health are few, with none ever conducted in Fiji. With the unavailability of reliable air quality data, this retrospective cohort study assessed the prevalence of acute respiratory infection ("ARI"), and compared the ARI-free survival rates of children born and living in a mining region and those born and living in a non-mining region, as a way of generalising the possible effects of gold mining-related air pollution on child health. This study also assessed the effectiveness of air pollution control programs conducted in the Vatukoula Gold Mine and Fiji.

Respiratory records and vital statistics of a cohort of children born in 2011 in both the regions were retrospectively followed up from birth until their fifth birthdays in 2016. Two groups were identified from the ARI dataset collected, those that had acute upper respiratory tract infection ("AURI") and those that had pneumonia. The incidence of AURI and pneumonia in the groups were estimated. The prevalent odds ratios were estimated for the exposed and the non-exposed cohorts, and their ARI-free survival rates were analysed using survival analysis. Key informant interviews and a focus group discussion were conducted to assess the effectiveness of air pollution management in Vatukoula Gold Mine.

Living in non-gold-mining region (Odds Ratio = 48) and children of Indo-Fijian race were at higher risk of AURI (Odds Ratio = 2.4). Further multivariable logistic regression showed living in non-gold-mining region as an independent risk factor for AURI (OR 39.6, 95% CI: 5.36 - 292; $p < 0.001$); while living in gold mining region was the single independent risk factor for pneumonia in this study ($p < 0.05$). Kaplan-Meier estimator showed living in gold mining region and I-taukei children having statistically significant AURI-free survival rates while living in the non-mining region had a statistically significant pneumonia-free rate at the end of first five years of life. Multivariable cox regression analysis showed living in the non-mining region was a statistically significant risk factor for AURI. Living in gold mining region was the only statistically significant risk factor for pneumonia after the univariate Cox proportional hazard analysis. While gold mining is the dominant activity in the gold mining region, the non-gold mining region is dominated by sugarcane farming. Air pollution from these two main activities may provide the possible explanations for the occurrence of the two acute respiratory infections (AURI and pneumonia) in the two regions.

Air pollution management and control activities by the management of Vatukoula Gold Mine are yet to meet the standards required to adequately sustain the environment and health of those living within its proximity. The unresolved air pollution issues of sulphur dioxide and dust at Vatukoula over the last eight decades are yet to be resolved. Those who have legal authority over the operation of the mine have done little to resolve these outstanding air pollution issues. The health of those residing near Vatukoula Gold Mine continues to be at risk from the effects of air pollution, as highlighted by previous studies, as well as this study.

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Abbreviation and glossary of terms

- AAP- Ambient Air Pollution
- ALRI - Acute lower respiratory tract infection
- AQMP - Air Quality Management Plan
- ARI - Acute respiratory tract infection and classified as upper respiratory infection or lower respiratory tract infection.
- ATSDR - Agency for Toxic Substances and Disease Registry
- AURI - Acute upper respiratory tract infection
- CI - Confidence Interval
- CO -Carbon monoxide
- CRO-VGM- Community Relation Officer, Vatukoula Gold Mine plc
- Crude Death Rate - Number of deaths per 1000 population in a given year.
- DALYs - Disability-adjusted burden of disease
- EBD - Environmental burden of disease
- EO-VGM - Environment Officer, Vatukoula Gold Mine plc
- EPA - Environmental Protection Agency
- FGP1 - Focus Group Discussion Participant No.1
- FGP2 - Focus Group Discussion Participant No.2
- GBD - Global burden of disease
- HFO - Heavy Fuel Oil
- IHME - Institute for Health Metrics and Evaluation
- Infant Mortality Rate - Number of deaths to infants under one year of age in a given year per 1000 live births in that year
- LMIC - Low- and middle-income countries
- MCH - Maternal and Child Health
- MoHMS - Ministry of Health and Medical Services
- MO-VGM - Medical Officer, Vatukoula Gold Mine
- NACD - National Advisor Communicable Diseases
- Neonatal Mortality Rate - The number of deaths to infants under 28 days of age in a given year per 1000 live births in that year.
- NO₂ -Nitrogen dioxide
- NO_x -Nitrogen oxides
- O₃ -Ozone

- OAP - Outdoor air pollution
- Pb -Lead
- Perinatal Mortality Rate - The number of foetal deaths after 28 weeks of pregnancy (late foetal death) plus the number of deaths to infants under 7 days of age per 1000 live births
- PIFS - Pacific Island Forum Secretariat
- PM -Particulate matter
- PM10 - Particulate matter less than 10 micrometer in diameter
- PM2.5 - Particulate matter less than 2.5 micrometer in diameter
- Post Neonatal Mortality Rate - The number of infant deaths at 28 days to one year of age per 1000 live births in a given year.
- RR - Relative risk
- SEO-DOE - Senior Environment Officer, Department of Environment
- SEO-MRD - Senior Environment Officer, Mineral Resource Department
- SES - Socio-economic status
- SHI - Senior Health Inspector
- SIO - Senior Information Officer
- SO2 -Sulfur dioxide
- TSP - Total suspended particles, or PM of any size.
- Under five Mortality Rate - The number of deaths to children under 5 years per 1000 live births during the year.
- VGM - Vatukoula Gold Mines plc.
- VTP - Vatukoula Treatment Plant
- WAF - Water Authority of Fiji
- WHO -World Health Organization
- YLL - Years of life lost

Chapter 1

Introduction

The World Health Organisation (WHO) estimated that approximately one in every nine death in 2012 was associated with exposure to air pollution[World Health organization, 2017]. It makes air pollution the most prominent environmental risk factor for ill health and the most significant environmental health crisis the world is facing. Ambient air pollution in 2012 was estimated to have caused 3.7 million deaths globally[WHO, 2014]. The low and middle income countries (LMICs) which represent 82% of the world population, had about 88% of these deaths[WHO, 2014]. Gold mining, a source of revenue for some LMICs, also poses a threat to the health of their local population. A handful of harmful air pollutants is generated from gold mining processes. Some include hydrogen cyanide, arsenic compounds, sulphur dioxide, silica and suspended particulate matter. These pollutants pose the highest risk to human health when they are not managed well. Cyanide is used to selectively leach gold from other metal ores during the cyanidation process [Kuyucak and Akcil, 2013]. This process produces large quantities of effluents which can contain free cyanide and a variety of metal-cyanide complexes [Ackley, 2008]. The first indication of cyanide poisoning includes rapid, deep breathing and shortness of breath, followed by convulsions (seizures) and loss of consciousness [ATSDR, 2006, Agyemang-Duah et al., 2016] . Breathing high levels of hydrogen cyanide is life-threatening and deadly [ATSDR, 2006].

A significant amount of sulphur oxides and arsenic trioxide are emitted to the atmosphere during the roasting of gold-containing ores to remove sulphur [Eisler, 2004]. Sulphur dioxide exposure causes breathing difficulty, changes in ability to breathe as profoundly or take in as much air per breath, and burning of the nose and throat[ATSDR, 1998]. Apart from the criteria pollutants, gold mining generates other harmful air pollutants including heavy metals. Gold mining activities contribute to the metal load of the environment[Getaneh and Alemayehu, 2006]. Arsenic oxide and sulfur oxide are by-products of roasting gold from arsenic[Wan, 2014]. Breathing high levels of inorganic arsenic is likely to cause sore throat and lung irritation [ATSDR, 2007]. Skin effects, circulatory, and peripheral nervous disorders are likely effects of lower level, long-term exposure. Inhalation of inorganic arsenic can increase lung cancer [ATSDR, 2007]. High levels (20-fold) of mean arsenic concentration were observed in the blood of adults and children in two mining communities (Trakwa Nsuaem Municipality/Prestea-Huni Valley District) than in a non-mining community (Cape Coast Metropolis), Ghana[Armah et al., 2012].

Residents near gold mine tailing dams are at unacceptable risk of exposure to crystalline silica. High levels of quartz (73-87%) with silica levels as high as 90 microgram/m³ and 51

microgram/m³ were noted in all dust samples collected from communities surrounding tailing storage facilities in Gauteng and the North-West, South Africa [Andraos et al., 2016]. Incidental nanoparticles were in large percentage indicating the potential of the dust to enter deep into the lungs. This increases the risk of respiratory diseases [Andraos et al., 2016]. Suspended particulate matter from the blasting of mineral bearing rocks contributed to respiratory disorders [Selvaraj et al., 2014, Yeboah, 2011, Agyemang-Duah et al., 2016].

Respiratory illness is one of the main health outcomes of concern in gold mining communities. Respiratory infection from mining communities in Obuasi, Ghana, was the result of air pollution emanating from the emission of dust and other chemicals into the air [Selvaraj et al., 2014, Yeboah, 2011, Agyemang-Duah et al., 2016]. It was among the top three diseases directly related to gold mining [Yeboah, 2011]. Health officials who were interviewed in this study also related ARI to air pollution. Acute respiratory infection was a health problem caused by mining as related by participants (70%) of a cross-sectional survey within four communities near the Newmont Ghana Gold Limited, Asutifi District, Ghana. A four-year assessment of the outpatient disease records in this district confirmed with the participant feedback that upper respiratory tract infection (URTI) was also second to malaria in the list of top ten diseases within the district. The risk of acute respiratory infections were almost 41- and 12-fold higher in two gold mining communities (Trakwa Nsuaem Municipality/Prestea-Huni Valley District) as compared to a non-mining community (Cape Coast Metropolis), Ghana [Armah et al., 2012]. The outpatient and inpatient ARI cases correspond with the high level of heavy metals present in the blood of adult and children, which was due to inhalation of toxic fumes in the two gold mining communities [Armah et al., 2012]. A study in Northern Chile in proximity to the mining industry and respiratory diseases indicated that the risk of respiratory diseases considerably increases closer to gold mine [Herrera et al., 2016]. There are fewer studies on impacts of gold mining on acute upper respiratory tract infection and pneumonia in children. No such study to specifically investigate the relationship between gold mining and both acute upper respiratory infection and pneumonia has ever been conducted in Fiji.

Acute respiratory infection continues to be the leading cause of morbidity and mortality for children under five years [Walke et al., 2014]. Worldwide, ARIs are the fourth leading cause of morbidity and mortality while they are one of the leading cause of death for children under five years. Yearly, an estimated 3.9 million children die worldwide of ARIs. The WHO estimated that approximately 20% of all deaths of children under five years are due to ARIs (pneumonia, bronchitis and bronchiolitis), where pneumonia accounts for 90% of all these deaths [Fakunle et al., 2014]. Globally, ARI is second to diarrhoeal diseases as a leading cause of death among children under five years [Kumar and Kalosona, 2016]. A significant proportion of cases occur in developing countries [Berman, 1991] and constitute a significant burden to child health [Mulholland, 2007, Liu et al., 2012]. The leading cause of death among children under five years in these countries are ARI, mainly of lower respiratory tract [Campbell, 1995, Victora et al., 2005, Wardlaw et al., 2006]. Globally, a large percentage (85-88%) of ARI cases are acute upper respiratory infections (AURI) with the remaining being acute lower respiratory infections (ALRI) [Tambe et al., 1999, Jain et al., 2001]. Pneumonia, an ALRI, was a most critical killer for children under five years in India, responsible for almost 28 % of all deaths [Collaborators, 2010]. The critical stage of growth and development of lung function makes young children more sensitive to environmental exposure [Liu et al., 2013]. However, generally, deaths from acute lower respiratory infection in children under 5 years has dropped significantly in the WHO East Asia and Pacific Region and also globally over the last one and half decades [WHO, 2016c]. These may have been attributed to the increased coverage of immunisation against certain infections such as pneumonia and measles. Nevertheless, in Fiji, the 2015 Ministry of Health Annual Report reported that ARI was still the leading cause of

morbidity in its population. It remained at the top of the list of notifiable diseases in the last decade and continued to increase over the years[Ministry of Health, 2016].

Poor management of acute respiratory infection can lead to complications. Typical cases are a complication of ear infections leading to deafness; and pharyngitis complications leading to rheumatic fever which can further develop into rheumatic heart disease, one of the severe diseases in developing countries[Simoes et al., 2006]. These are challenges faced by developing countries. Therefore, understanding risk factors and proper management of ARIs in children should be an area of importance to public health.

Children are a vulnerable group in communities. They are vulnerable to air pollution, climate change, hazardous chemicals, and inadequate water, sanitation and hygiene[WHO, 2018a]. Out of all these risks, air pollution is the greatest environmental risk to children's health[WHO, 2018a]. It is estimated that annually, more than 570,000 children under five years die from respiratory diseases, such as pneumonia, linked to indoor and outdoor air pollution and second-hand tobacco smoke[WHO, 2018a]. Occupational exposure of parents to heavy metals can also endanger the health of their children. A typical example is children at risk of being exposed to metallic mercury that may be brought home by their parents either through work clothes or tools, or to methylmercury contaminated food. Inorganic mercury and methylmercury can also pass from a mother's body into breast milk and into a nursing infant. The amount of mercury in the milk will vary, depending on the degree of exposure and the amount of mercury that enter the nursing woman's body[ATSDR, 2015b].

This study focused on acute upper respiratory infection (AURI) and pneumonia. The upper respiratory tract comprised of the airways from the nostrils to the vocal cords in the larynx, and include the paranasal sinuses and the middle ear. The continuation of the airways from the trachea and bronchi down the bronchioles and alveoli are regarded as the lower respiratory tract[Simoes et al., 2006]. Acute upper respiratory tract infections are those infections that affect the upper respiratory tract while pneumonia affects the lower respiratory tract, mainly the lungs.

Developing countries with mineral reserves always face challenges in addressing environmental, safety and health issues when extracting these minerals. Kwesi and Kwasi (2011) stated that government in developing countries lack the ability to strengthen these areas to reap the full benefits of such industries [Amponsah-Tawiah and Dartey-Baah, 2011]. Findings from Ackley [Ackley, 2008] on gold mining environmental risks at Vatukoula Gold Mine, Fiji, highlighted the lack of legislation in developing countries to take into consideration the environmental performance of mining activities. This same study also highlighted the lack of knowledge amongst community members on mining risks together with their increasing concern for health impacts. In this risk perception study, gender plays an important role where women have less knowledge about mining risk and also have less control to avoid the risk of mining as compared to men. The highest risk of concern amongst participants (74.5%) in this study was air pollution. Participants stated that they were "anxious" about this risk. A large proportion of participants (85%) felt that air pollution is "somewhat" or "very" likely to have harmed their health. Almost 90% of parents stated that they were worried about their children's health as they live close to the mine; with 85% felt worried that degraded environment will affect their future generations. These findings reflect the level of commitment by the mine management and those in authority to address environmental and health impacts of this industry.

1 Research rationale

Mining in Fiji has intensified over the last decade. According to Fiji's Prime Minister, Mr Voreqe Bainimarama, a total of 49 Special Exploration Licenses were issued until 2011 while a further 37 applications, including deep sea explorations, were under process[Fijian Government, 2011b]. The mining industry is a source of revenue for this small island country. Given the huge potential of mining globally and locally as a source of revenue, employment, and other benefits, its darker side is an area that is always given less priority. Environmental health-related illness as a result of environmental pollution from mines wastes is common. There are more studies conducted on impact of gold mining on water, soil and vegetation quality with less on air quality. As the mining industry in Fiji grows, it is inevitable that the environmental health impacts will also increase. There are fewer studies on impacts of gold mining on acute upper respiratory tract infection and pneumonia in children. No study has ever been conducted in Fiji to specifically investigate the relationship between gold mining and both acute upper respiratory infection and pneumonia.

This study focused on children under five years as they are amongst the most vulnerable in society. It is a critical period of their development and growth. Much of their growth and health depend on their immediate environment. The promotion of good health in this age group is of critical importance and have been part of both global goals, i.e., the last Millennium Development Goals (MDGs) 2015 and its replacement, the Sustainable Development Goals (SDGs) 2030. Ensuring healthy lives and promoting well-being for all at all ages is Goal 3 of the SDG. Reduction of deaths for children under 5years and reduction of deaths and illnesses associated with poor environmental conditions are two targets under this goal [World health Organization, 2017]. While the focus nowadays is on the global effect of air pollution on climate change and its associated impacts, the immediate impacts of point-source air pollution on their immediate population should not be underestimated. A healthy environment is, therefore, important for protection and promotion of children's health at the early stage of growth.

The burden of acute respiratory infections is more in low and middle income countries. Air quality in these countries is mostly unknown due to the lack of air quality data. While the acute lower respiratory infection is a predominant problem in developing countries, most of the studies are concentrated in developed countries.[Dharmage et al., 1996]. Measuring air quality is a challenge in Fiji due to lack of appropriate funding, human resources and capacity from those legally responsible to protect air quality. The Waste Disposal and Recycling Regulations 2007 requires every commercial or industrial facility that emits exhaust gases, smoke, steam or dust from any of its premises to hold an air pollution permit and to also monitor air quality at their exhaust emission points. However, the respondents to this study have indicated that the practical implementation and enforcement of this legal requirement are deficient. Therefore relating respiratory illnesses to poor air quality is a challenge. The study of exposed and non-exposed groups to specific air pollution exposure like gold mining, as in this case, was useful to generalise the possible associations between poor air quality and acute upper respiratory infections (AURI) and pneumonia. This study investigated the relationship between gold mining and the prevalence of AURI and pneumonia in children under five years. It was crucial to understanding air quality as one of the primary determinants of health. This is the first study ever to be conducted in Fiji that investigated the likelihood of poor air quality relating to gold mining activities impacting the health of children under five years. Past studies conducted in Fiji mostly describe respiratory infections in general, but less have linked them to a particular risk factor as in this study. Also, there was no study found or conducted locally that described the relationship between gold mining and ARI, making this study the first of its kind in Fiji.

2 Research scope

This thesis report presents the findings of a retrospective cohort study of a 2011 birth cohort of children comprising of a group from a gold mining region and a group from a non-gold mining region. The focus of the study was to compare the prevalence of acute upper respiratory infection (AURI) and pneumonia, and the AURI-free and pneumonia-free survival rates of children born and raised in the two regions. The attention was on the likelihood of gold mining-related air pollution affecting respiratory health of children. Children were selected due to their vulnerability to air pollution and the likelihood of air pollution having a critical impact on their growth and development.

Due to the unavailability of reliable air quality data in the gold mine, and the time limit for this thesis project, the retrospective cohort study was identified as the most appropriate study design to highlight the possible impact of gold mining-related air pollution on child respiratory health. Acute respiratory infection profile of each group of children in this cohort were observed from birth until they reached their fifth birthday in 2016. Data on respiratory status of these children were retrieved from the nurses responsible for the nursing zones that were engaged in this study. Data for this study was limited to only those that were collected by IMCI nurses when classifying respiratory infections in their clinics as either "no pneumonia cough or cold", the milder form and affects the upper respiratory tract; "pneumonia" and severe pneumonia or severe disease" which affects the lungs.

This study also gathered information on the effectiveness of air pollution control and management programs conducted at Vatukoula Gold Mine and the programs conducted by the various government department for Vatukoula and the country. This is an essential aspect of this study as it documents the current activities conducted, their effectiveness, the challenges and the prospect of air pollution works in Fiji. While much deliberation in Fiji is on climate change, the local air pollution level should be an immediate indicator of how the country is progressing in reducing its carbon emission. Not only climate change programs are essential to meeting global targets, but the immediate effects of those programs also likely directly benefit the respiratory health of the local population. Further to this, the representatives from the Ministry of Health and Medical Services highlighted some of the programs that are improving the health of children under five years in Fiji.

3 Research questions

The research questions for this study were based on assessing the likely impact of gold mining air pollution on the health of children under five years; and the effectiveness of the Vatukoula Gold Mine to control and manage air pollution. Therefore, the null hypothesis of this study stated that the prevalence of AURI and pneumonia, and the AURI-free and pneumonia-free rates for children born and raised in the gold mining for the first five years of life are similar to those children that were born and raised in the non-gold mining regions. The alternate hypothesis stated that these rates were different in the two groups. The second objective of this study questioned the effectiveness of the air pollution management and control programs implemented by Vatukoula Gold Mine and the roles of the various government departments in addressing air pollution issues in Vatukoula and Fiji.

4 Goals and objectives

The goal of this study was to find out whether gold mining increases the risk of acute upper respiratory infection and pneumonia for children under five years living in Vatukoula, Fiji. Three objectives were set: (a) to describe and compare the first AURI and pneumonia prevalence rates, and to compare the AURI-free and pneumonia survival rates in the first five years of life for children in the mining region and the non-mining region; (b) to identify and assess the effectiveness of existing air pollution control activities implemented at Vatukoula Gold Mine to protect human health; and (c) to recommend way forward on ways to protect human health from poor air quality in the mining community and in Fiji. The null hypothesis states that the first AURI and pneumonia prevalence rates and AURI-free and pneumonia survival rates are similar for children under five years living in gold mining region and those living non- gold mining region. The alternate hypothesis states that children under five years living in the gold mining region have higher first AURI and pneumonia prevalence rates, and survival rates, for the first five years of life than those not living near a gold mine.

5 Significance of research

This study involved the retrospective study of children acute respiratory infection records with their association to gold mining-related air pollution. The Vatukoula Gold Mine has existed for over eight decades with air pollution, mainly sulfur dioxide and dust, as the two main air pollution of concern to the Vatukoula community since the 1930s. This is the first study in Vatukoula to assess the possible impacts of gold mining air pollutants on the respiratory health of children under five years. This research is also significant as it is the first in the country to use the Kaplan-Meier estimator to assess the survival rates of children from acute upper respiratory infection and pneumonia in the first five years of life. Further to this, this may also be the first study to assess the effectiveness of the roles of the various government departments in addressing air pollution in the gold mining sector and in Fiji.

Chapter 2

Literature review

1 Association between air quality and acute respiratory infections

1.1 Sources of Air Pollution

The WHO defines air pollution as the "contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere"[WHO, 2017a]. Pollution sources ranges from household energy sources, motor vehicles, industries to forest fires. The five pollutants of major public health concern to public health listed by WHO are ozone, particulate matter, carbon monoxide, sulphur dioxide and nitrogen dioxide[WHO, 2017a]. The EPA has added lead (Pb) to the WHO list above as the sixth air pollutants for six common air pollutants in the US, which are also known as "criteria air pollutants"[EPA, 2017c]. These pollutants are important as they all affect human health and the environment, and can also damage property[EPA, 2017c]. From the six pollutants, four (CO, Pb, NO₂, and SO₂) are emitted directly from a variety of sources; ozone is not directly emitted, but formed after reaction of oxides of nitrogen (NO_x) and volatile organic compounds (VOC) in the presence of sunlight; while PM can be emitted or can be formed when emissions of NO_x, sulfur oxides (SO_x), ammonia, organic compounds and other gases react in the atmosphere[EPA, 2017a]. Air pollution is a global issue, affecting individuals across all countries and socio-economic groups. "Excessive air pollution is often a by-product of unsustainable policies in sectors such as transport, energy, waste management and industry," says Dr Carlos Dora, WHO Coordinator for Public Health, Environmental and Social Determinants of Health.

Air pollution is produced by the natural or human-caused release of harmful contaminants into the atmosphere. Air pollutants in the atmosphere can either be primary or secondary sources. Primary air pollutants are those generated from emissions while secondary air pollutants are those formed within the atmosphere itself[WHO, 2005]. Primary air pollutants include oxides of nitrogen, carbon monoxide, sulphur dioxide, volatile organic compounds, and carbonaceous and noncarbonaceous primary particles. These primary pollutants are emitted to the atmosphere from sources such as vehicle exhaust pipe or from a factory chimney, or by the suspension of contaminated dusts by the wind[WHO, 2005]. It is possible to measure the amount of emissions from a vehicle exhaust or a factory chimney as it is relatively straightforward, but not so for

diffuse sources such as wind-blown dusts[WHO, 2005]. Secondary air pollutants is a product of chemical reaction of primary pollutants in the atmosphere, possibly involving natural components of the environment such as oxygen and water[WHO, 2005]. Ozone, oxides of nitrogen and secondary particulate matter are the most prominent secondary pollutants. Ozone, the most familiar of them, is mainly a product from chemical reactions that differ with altitudes within the atmosphere. It is not always easy to keep emission inventories of secondary pollutants as compared to primary pollutants, however it is possible to estimate formation rates per unit volume of atmosphere per unit time. The physical state of a pollutant is another factor that distinguishes primary and secondary pollutant[WHO, 2005].

Air pollutants can either be in gaseous or particulate form. Gaseous air pollutants can appear as gases or vapours in individual small molecules capable of passing through filters but should not adsorb to or chemically react with the filter medium. Gaseous air pollutants are easily taken into the human respiratory system, and may very easily deposited in the upper respiratory tract if water-soluble, therefore, not penetrating to the deep lung. On the other hand, particulate air pollutants are materials in solid or liquid phase suspended in the atmosphere[WHO, 2005]. They can either be primary or secondary and cover a wide range of sizes; with secondary particles as small as 1-2nm in diameter where as coarse dust and sea salt particles as large as 100micrometer or 0.1 mm diameter. The very large particles have short atmospheric existence, therefore, falling out rapidly through gravity and wind-driven impaction processes[WHO, 2005]. There are a few particles in the atmosphere exceeding 20 micrometer in diameter, except in locations close to the emission sources. Drawing air through a filter fine enough to retain the particles can be used to separate particulate matter from the atmospheric gases. The chemical composition of particulate matter are very diverse highly depending on their source; and also diverse in particulate size[WHO, 2005]. PM10 and PM2.5 and ultrafine particles fractions are the common particulate air pollutants measured within the atmosphere for the purpose of health effects studies[WHO, 2005].

While some pollutants are localized, some are concentrated in urban areas, some can be transported to regional scale with some to hemispheric and global scales; depending on their atmospheric lifetime[WHO, 2005]. Local scale pollutants have very short atmospheric lifetime, and tend to concentrate only close to their emission source. Two of the most prominent urban air pollutants, nitrogen oxides and carbon monoxide, have high concentrations in urban and city areas as compared to adjacent rural areas. However, they only have hours of atmospheric lifetime and therefore their concentrations in remote atmospheric background is likely to be low, except for carbon monoxide which is more persistent[WHO, 2005]. Those pollutants with atmospheric lifetime of days and even weeks permit them to be transported on a regional scale. These include fine particulate (<PM2.5 and not ultrafine particles), some gas-phase pollutants such as ozone, and including fine aerosol (particles) of black carbon arising from the burning of fossil fuels and biomass. Sulphate particles and ozone have the capacity to travel thousand of kilometers, crossing national boundaries during this long-range transport. Pollutants such as carbon dioxide, nitrous oxide and methane have atmospheric lifetime of years. These pollutants are commonly associated with greenhouse warming effects and have the capacity of being distributed throughout a hemisphere and ultimately globally. Unless the sources emit very large quantities, the concentration of these pollutants are often marginally higher close to sources as compared to the regional background[WHO, 2005].

1.2 Criteria pollutants sources

Particulate Matter

Particulate matter (PM), also called particle pollution is a complex mixture of extremely small particles and liquid droplets that get into the air[EPA, 2017c]. Most PM particles form in the atmosphere as a result of chemical reactions between pollutants[EPA, 2017f]. The major components of PM are sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water. It consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air[WHO, 2017b]. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye. Others are so small they can only be detected using an electron microscope[EPA, 2017f]. Particle pollution includes PM₁₀ and PM_{2.5}. PM₁₀ are inhalable particles, with diameters that are generally 10 micrometers and smaller, while PM_{2.5} are fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller[EPA, 2017f]. PM_{2.5} is 30 times smaller than the size of an average human hair which is about 70 micrometers in diameter[EPA, 2017a]. Particulate matters come in many sizes and shapes and can be made up of hundreds of different chemicals. They are emitted to the environment from sources such as unpaved roads, fields, construction sites, smokestacks or fires[EPA, 2017a]. In power plants, industries and automobiles, complex reactions of chemicals such as sulphur dioxide and nitrogen oxides contribute most particles in the atmosphere[EPA, 2017f]. The WHO guideline values for PM_{2.5} are 10 microgram/m³ as annual mean, and 25 microgram/m³ as 24-hour mean; while for PM₁₀, it is 20 microgram/m³ as annual mean and 50 microgram/m³ as 24-hour mean[WHO, 2017b]. Measurement of PM_{2.5} are widely conducted in high-income countries, whereas not readily available in many LMICs[WHO, 2016a]. However, the WHO has recognized an improvement in the last three years[WHO, 2016a].

Sulphur dioxide

Sulphur dioxide (SO₂) is one of a group of gases called sulfur oxides (SO_x)[EPA, 2017c]. About 99% of the sulfur dioxide in air comes from human sources. All of them are harmful to human health and the environment, however, SO₂ is of greater concern[EPA, 2017c]. The SO₂ is used as the indicator for the larger group of gaseous sulfur oxides. It is a colorless gas with a sharp odour. Other SO_x gases are at much lower concentrations than SO₂ in the atmosphere. This SO₂ is produced from the burning of either sulfur or materials containing sulfur[EPA, 2017g], i.e., burning of fossil fuels (coal and oil for domestic heating, power generation and motor vehicles) and the smelting of mineral ores that contain sulfur[WHO, 2017b]. Fossil fuel combustion at power plants and other industrial facilities are the largest sources of SO₂ emissions. The sulfur content in fossil fuels, most notably coal and oil, varies according to their sources, but typically between 1% and 5%[WHO, 2005]. The combustion of fossil fuel quantitatively converts the sulfur into sulphur dioxide. The sulphur dioxide emissions in vehicles from developed countries is minimal due to the removal of much of the sulfur from motor fuels in the refining process and from stack gases prior to emission[WHO, 2005]. The less volatile fractions of crude oil abundantly have more sulfur and hence shipping can be a very high emitter of sulphur dioxide as it burns residual fuel oil. Emissions that lead to high concentration of SO₂ also lead to formation of other SO_x. Smaller sources of SO₂ emissions include: industrial processes such as extracting metal from ore which involves roasting metal sulfide ores in a stream of air; locomotives, ships and other vehicles and heavy equipment that burn fuel with a high sulfur content; and natural sources such as volcanoes[EPA, 2017g]. The current WHO guideline values for SO₂ are 20 microgram/m³ as

24-hour mean and 500 microgram/m³ as 10-minute mean. The main sources of sulphur dioxide in less developing countries include the unabated burning of coal and use of oils and automotive diesel with high sulfur content[WHO, 2005].

Ozone

Ozone is found both in the Earth's upper atmosphere and at ground level. The stratospheric ozone is classified as good ozone as it forms a protective layer that shields us from the sun's harmful ultraviolet rays[EPA, 2017a]. The tropospheric, or ground level ozone is usually regarded as bad ozone due to its harmful effects to the people and the environment, and is the main ingredient in "smog"[EPA, 2017e, WHO, 2017b]. This ozone is a product from the chemical reactions between oxides of nitrogen (NO_x) and volatile organic compounds (VOC) in the presence of sunlight[EPA, 2017e, WHO, 2017b]. Some major sources of NO_x and VOC are emissions from industrial facilities and electric utilities, gasoline vapors motor vehicle exhaust and chemical solvents[EPA, 2017e]. Unhealthy levels of ozone pollution can be reached during period of sunny weather[EPA, 2017e, WHO, 2017b]. High levels can also be experienced during colder months. Rural areas can experience high ozone levels as ozone can be transported long distances by wind[EPA, 2017e]. The WHO guideline values for ozone are 40 microgram/m³ annual mean and 200 microgram/m³ 1-hour mean.

Carbon monoxide

The incomplete combustion of carbon-containing fuel produces carbon-monoxide while the complete combustion produces carbon dioxide[WHO, 2005]. However, most combustions systems involve some fuel-rich regions, e.g., the combustion of petrol in road vehicles, where a proportion of carbon is oxidized only to carbon monoxide[WHO, 2005]. Carbon monoxide is a colorless and odorless gas[EPA, 2017c]. The greatest sources of CO to outdoor air are cars, trucks and other vehicles or machinery that burns fossil fuels[EPA, 2017c]. Indoor sources can be from unvented kerosene and gas space heaters, leaking chimneys and furnaces, and gas stoves[EPA, 2017b].

Oxides of nitrogen

Similar to the sulphur dioxide production during fuel combustion, nitrogen in fuels is converted to oxides of nitrogen in the combustion process. Coal has higher level of nitrogen as compared to oil and gas. Oxides of nitrogen are further produced when the atmospheric nitrogen and oxygen combine in all high-temperature combustion processes; with road traffic and electricity generation tend to be amongst the predominant sources of these gases[WHO, 2005]. The majority of nitrogen oxides formed through this high-temperature combustion are emitted as nitric oxide. Approximately 5% of atmospheric nitrogen dioxide is from primary sources while a major proportion is a secondary product of atmospheric chemistry[WHO, 2005].

Nitrogen Dioxide (NO₂) is one of a group of highly reactive gases known as oxides of nitrogen or nitrogen oxides (NO_x)[EPA, 2017c]. Nitrous acid and nitric acid are other nitrogen oxides. The indicator for the larger group of nitrogen oxides is NO₂. The NO₂ primarily gets into the air from the burning of fuel. Nitrogen dioxide is produced from emissions from cars, trucks and buses, power plants, and off-road equipment[EPA, 2017d, WHO, 2017b]. Air quality and visibility may be affected due to presence of high levels of nitrate particles that result from NO_x, making the

air hazy and difficult to see[EPA, 2017d]. The NO₂ is the source of nitrate aerosols, which form an important fraction of PM_{2.5} and, in the presence of ultraviolet light, of ozone[WHO, 2017b]. The interaction of NO₂ and other NO_x with water, oxygen and other chemicals in the atmosphere form acid-rain, which is harmful to sensitive ecosystems[EPA, 2017d]. The current WHO guideline values for NO₂ are 40 microgram/m³ as annual mean and 200 microgram/m³ as 1-hour mean[WHO, 2017b].

Volatile organic compounds (VOC)

Volatile organic compounds, sometimes referred to as VOCs, are organic compounds that easily become vapors or gases. These include a wide range of oxygenates, halogenates, hydrocarbons and other carbon compounds existing in the atmosphere in the vapour phase[WHO, 2005]. Along with carbon, they contain elements such as hydrogen, oxygen, fluorine, chlorine, bromine, sulfur or nitrogen. Possible emission sources include: leakage from pressurized systems (e.g., natural gas, methane); evaporation of liquid fuel such as benzene from fuel tank of vehicles; fossil fuel combustion and incineration processes.

1.3 Health effects of criteria air pollutants

The WHO reveals that air pollution levels remain dangerously high in many parts of the world. Data from the organization indicated that 9 out of 10 people breath air containing high levels of pollutants[World Health Organization, 2018a]. Recent estimates states that ambient (outdoor) and household air pollution contributed to an alarming death toll of 7 million people yearly. The Director General of WHO, Dr Tedros Adhanom Ghebreyesus said in a recent WHO press release on 2nd May 2018 that even though air pollution threaten us all, the full brunt of the burden are felt by the poorest and most marginalized people[World Health Organization, 2018a]. Also highlighted in this release is the fact that 3 billion people globally, mostly women and children are still highly exposed to deadly indoor pollutants especially from use of polluting stoves and fuels in homes. Air pollution has been acknowledged by WHO as a critical risk factor for non-communicable diseases (NCDs), causing approximately 24% of all adult deaths from heart disease, 42% from chronic obstructive pulmonary disease, 25% stroke and 29% from lung cancer.

Health effects of air pollution can be attributed to short-term and long-term exposure. The Air Quality Guidelines - Global Update 2005 lists short-term exposure effects which include daily mortality; respiratory and cardiovascular hospital admissions; respiratory and cardiovascular emergency department visits; respiratory and cardiovascular primary care visits; use of respiratory and cardiovascular medications; days of restricted activity; work absenteeism; school absenteeism; acute symptoms (wheezing, coughing, phlegm production, respiratory infections); and physiological changes (e.g. lung function)[WHO, 2005]. It also lists long-term exposure effects as mortality due to cardiovascular and respiratory disease; chronic respiratory disease incidence and prevalence (asthma, COPD, chronic pathological changes); chronic changes in physiologic functions; lung cancer; chronic cardiovascular disease; intrauterine growth restriction (low birth weight at term, intrauterine growth retardation, small for gestational age)[WHO, 2005]. Both indoor and outdoor pollution cause respiratory and other diseases, which can be fatal[WHO, 2017a].

The WHO recognizes that when air quality in an area declines, the risk of stroke, heart disease, lung cancer, and chronic and acute respiratory diseases, including asthma, increases for the people who live in them[World Health Organization, 2017b]. The lower the levels of air

pollution, the better the cardiovascular and respiratory health of the population will be, both long- and short-term[WHO, 2017b]. The WHO estimated that approximately 80% of people living in urban areas that monitor air pollution are exposed to air quality levels that exceed the WHO limits[World Health Organization, 2017b]. In 2014, it was estimated that 92% of the world population were living in places where the WHO air quality guidelines levels were not met[WHO, 2017b]. The worst affected are those living in low-and middle income countries. Outdoor air pollution is a major environmental health problem affecting everyone in developed and developing countries alike[WHO, 2017b]. A notable increase in cities measuring air quality levels and recognizing the associated health impacts was seen in the last two years[World Health Organization, 2017b].

The health effects of exposure to a substance (hazard) are determined by many factors. These include the dose (how much), the duration (how long), and how you come in contact to it[ATSDR, 2015b]. Present of other chemicals, together with the person's age, sex, diet, family traits, lifestyle, and state of health are other factors that should be considered[ATSDR, 2015b]. Proximity to air pollutant point source was statistically significantly associated with increasing respiratory symptoms in a study conducted in southwestern British Columbia[Clark et al., 2010].

Impacts of air pollution in developing countries

In 2016, the latest WHO air quality database indicated that 98% of cities in low- and middle income countries (LMIC) with more than 100 000 inhabitants do not meet WHO air quality guidelines[World Health Organization, 2018c]. Nevertheless, the percentage decreases to 56% in high-income countries. Current air quality data are mostly for urban towns and cities. The WHO reported that for those living in urban areas that monitor air pollution, more than 80% of them are exposed to air quality levels that exceed the WHO limits[World Health Organization, 2018c]. The impact of air pollution is extremely felt in low and middle income countries. The WHO estimated that more than 90% air pollution-related deaths occur in such countries, mainly in Asia and Africa and followed by Eastern Mediterranean region, Europe and the Americas.

A significant inequality exists in the exposure to air pollution and related health risk. The less affluent part of societies face a disproportional disease burden as air pollution combines with other aspects of physical and social environment. Issues such as poverty and social deprivation exaggerate the effects of air pollution in these developing countries. In 2012, ambient air pollution in both cities and rural areas was estimated to cause 3 million premature deaths worldwide[WHO, 2017b]. An estimated 88% of these deaths occurred in low and middle-income countries, with WHO Western Pacific and South-East Asia regions having the greatest number[WHO, 2017b]. This mortality is due to exposure to small particulate matter of 10 microns or less in diameter (PM₁₀), which cause cardiovascular and respiratory disease, and cancers[WHO, 2017b]. The low and middle income countries are at higher risk of exposure to both indoor and outdoor air pollution. Outdoor air pollution is not the only risk to human health in terms of air quality, but also indoor smoke which poses a serious health risk for some 3 billion people who cook and heat their homes with biomass fuels and coal[WHO, 2017b]. Some 4.3 million premature deaths were attributable to household air pollution in 2012. Almost all of that burden was in low-middle-income countries as well.

Particulate matter

Particulate matter affects more people than any other pollutant[WHO, 2017b]. Particulate matter less than 10 micrometers, which contains microscopic solids or liquid droplets that are so small that they can be inhaled, cause serious health problems[EPA, 2017f]. The PM₁₀ or less are the most health-damaging particles due to their ability to get deep into your lungs, and some may even get into the bloodstream. The greatest potential health-damaging effect is caused by the PM_{2.5}, which has a smallest diameter of 2.5 micrometer[Rehfuess et al., 2006, EPA, 2017f, WHO, 2017b, Kuti et al., 2013]. Once inhaled, particulate matter can affect the heart and cause serious health effects[EPA, 2017f]. Fine particles (PM_{2.5}) are the main causes of reduced visibility. The PM affects more people than any other pollutant[Kumar and Kalosona, 2016]. Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases, as well as of lung cancer[EPA, 2017f, Burnett et al., 2014]. Increased PM_{2.5} level was found to be associated with increased occurrence of respiratory illness in children[Kumar et al., 2014]. Studies have shown a close, quantitative relationships between exposure to high concentrations of small particulates (PM₁₀ and PM_{2.5}) and increased mortality or morbidity, both daily and over time[WHO, 2017b]. On the other hand, when concentrations of small and fine particulates are reduced, related mortality will also go down – presuming other factors remain the same. Even at very low concentrations, small particulate pollution does have health impacts[WHO, 2017b]. Lowering the concentrations of particulate matter in per meter cube of an area will significantly reduce the risk for acute and chronic health effects[WHO, 2017b]. Apart from outdoor air pollution, the developing countries also face a huge threat from indoor exposure to pollutants from the household combustion of biomass on open fires or traditional stoves increases the risk of acute lower respiratory infections and associated mortality among young children; indoor air pollution from biomass use is also a major risk factor for cardiovascular disease, chronic obstructive pulmonary disease and lung cancer among adults[WHO, 2017b]. The millions of death reported by WHO every year is a result of exposure to fine particles in polluted air that penetrate deep into the lungs and cardiovascular system, causing diseases such as stroke, lung disease, heart disease, chronic obstructive pulmonary diseases and respiratory infections, including pneumonia[World Health Organization, 2018a].

Children are vulnerable to the effect of exposure to particulate matter. Exposure to PM affects lung development in children, including reversible deficits in lung function as well as chronically reduced lung growth rate and a deficit in long-term lung function. There is no evidence of a safe level of exposure or a threshold below which no adverse health effects occur. The exposure is ubiquitous and involuntary, increasing the significance of this determinant of health. Early life exposure to ambient PM₁₀ was statistically significantly associated with increasing respiratory symptoms in studies conducted in Taiwan and southwestern British Columbia[Hwang and Lee, 2010, Clark et al., 2010]. Exposure to ambient particulate matter (PM_{2.5} and PM₁₀) in four Chinese cities was associated with decreased development of lung function[Roy et al., 2012]. However, a study conducted in California found no association between ambient PM₁₀ and respiratory symptoms in children[Peters et al., 1999].

Sulphur dioxide

While all sulfur oxides are harmful to human health and the environment, sulfur dioxide is of the greatest concern[EPA, 2017c]. When breathed in, it irritates the nose, throat, and airways to cause coughing, wheezing, shortness of breath, or a tight feeling around the chest[DOE, 2005]. The effects of sulphur dioxide are felt very quickly and most people would feel the worst symptoms

in 10 or 15 minutes after breathing it in[DOE, 2005]. Short-term exposures to SO₂ can harm the human respiratory system, make breathing difficult, affect lung functions, and cause irritation of the eyes[EPA, 2017g, WHO, 2017b]. The inflammation of the respiratory tract causes coughing, mucus secretion, aggravation of asthma and chronic bronchitis and makes people more prone to infections of the respiratory tract[WHO, 2017b]. Children, the elderly, and those who suffer from asthma are particularly sensitive to effects of SO₂[EPA, 2017g]. Other SO_x can react with other compounds in the atmosphere to form small particles, therefore, contributing to particulate matter (PM) pollution that may penetrate deeply into sensitive parts of the lungs causing additional health problems[EPA, 2017g]. Higher SO₂ levels are associated with increased hospital admissions for cardiac disease and mortality[WHO, 2017b]. Apart from impact to the respiratory system, atmospheric SO₂ and other SO_x can contribute to acid rain, polluting and affecting sensitive ecosystems that man depend on for living[EPA, 2017g]. The SO₂ combines with water to form sulfuric acid; the main component of acid rain[WHO, 2017b].

Sulphur dioxide is highly soluble and readily absorbed in the upper respiratory tract. The response to sulphur dioxide is rapid, occurring within the first few minutes of exposure[WHO, 2010]. The acute effects of sulphur dioxide exposure include reductions in lung function (e.g. FEV₁), increases in airway resistance and symptoms such as wheezing and shortness of breath[WHO, 2010]. These effects are enhanced when breathing is through the mouth as commonly occurs during exercise or heavy exertion. Information on the acute effects of sulphur dioxide has come primarily from controlled exposure studies using volunteers. One of the general findings from these studies is that there is a continuous spectrum of sensitivity to sulphur dioxide, with some people being completely unaffected by concentrations that lead to severe bronchoconstriction in others[World Health Organisation, 2000]. The long-term effects of sulphur dioxide exposure are not clear, particularly the question whether sulphur dioxide actually causes lung disease. This in part is due to the difficulty in distinguishing the effects of this gas from those of other air pollutants[WHO, 2010]. Early life exposure to ambient SO₂ was statistically significantly associated with increasing respiratory symptoms in a study conducted in southwestern British Columbia[Clark et al., 2010].

Ozone

Excessive ozone in the air can have a marked effect on human health[WHO, 2017b]. Children, the elderly and people of all ages with lung diseases such as asthma, are at higher risk of developing a variety of health problems when exposed to ozone[EPA, 2017e]. A variety of health problems can be triggered by breathing ozone, and include chest pain, coughing, breathing problem, throat irritation, and airway inflammation[EPA, 2017e, WHO, 2017b]. It also has the ability to reduce lung function, harm lung tissue, worsen bronchitis, emphysema, and asthma, leading to increased medical care[EPA, 2017a]. Ozone is currently one of the air pollutants of most concern in Europe due to its association with mortality and heart diseases. Studies in Europe indicated that daily mortality rises by 0.3% and that for heart diseases by 0.4%, per 10 microgram/m³ increase in ozone exposure[WHO, 2017b].

Carbon monoxide

High concentrations of carbon monoxide when inhaled reduces the amount of oxygen that can be transported in the blood stream to critical organs like the heart and brain[EPA, 2017b]. Dizziness, confusion, unconsciousness and death can occur when inhaling very high levels of

CO, mainly indoor or in other enclosed environments. Elevated levels of outdoor CO can be a concern to people with some types of heart diseases especially in situations where they are exercising or under increased stress[EPA, 2017b]. It is unlikely that carbon monoxide has any direct effects on the lung tissue except at extremely high concentrations. Its toxic effects on humans are due to hypoxia, which becomes evident in organs and tissues with high oxygen consumption such as the brain, the heart, exercising skeletal muscle and the developing fetus[World Health Organisation, 2000]. Early life exposure to ambient CO was statistically significantly associated with increasing respiratory symptoms in a study conducted in southwestern British Columbia[Clark et al., 2010].

Nitrogen dioxide

While all nitrogen oxides are harmful to human health and the environment, NO₂ is of greater concern[EPA, 2017c]. Exposure to high concentration of NO₂ can irritate the human respiratory system[EPA, 2017c, WHO, 2017b]. A short-term exposure at concentrations exceeding 200 microgram/m³ is toxic, which causes significant inflammation of the airways[WHO, 2017b]. These exposures over a short periods can make respiratory diseases worse, mainly asthma, leading to respiratory symptoms (such as coughing, wheezing or difficulty breathing, hospital admission and visits to emergency rooms[EPA, 2017d]. Asthma may also develop after longer exposure to elevated NO₂ concentrations, and potentially increase susceptibility to respiratory infections[EPA, 2017d, WHO, 2017b]. Epidemiological studies have shown that long-term exposure to NO₂ increases the symptoms of bronchitis in asthmatic children[EPA, 2017d, WHO, 2017b]. Current concentrations of NO₂ measured in cities of North America and Europe are associated with reduced lung function growth[WHO, 2017b]. Children, elderly and asthmatic people are at greater risk for the health effects of NO₂[EPA, 2017d]. The NO₂ and other NO_x have the ability to react with other chemicals in the air to form both particulate matter and ozone; which are both harmful when inhaled due to their effects on the respiratory system[EPA, 2017d]. Early life exposure to ambient NO was statistically significantly associated with increasing respiratory symptoms in a study conducted in southwestern British Columbia[Clark et al., 2010]. A population-based nested case-control study found that prevalence of respiratory symptoms was associated with increased NO₂ concentration (clark2010effect). However, two China studies and a California study did not show any relationship between NO₂ and respiratory symptoms in children[Zhang and Liu, 2002, Zhao et al., 2008, Peters et al., 1999].

Other pollutants

Heavy metals

Gold mining exposes a variety of heavy metals. Even though most heavy metals at low concentrations play important roles as nutrients for animals, plants and human health, some when available at high quantities and in certain forms may be harmful to lives as they may be toxic[Getaneh and Alemayehu, 2006]. Two good examples are copper (Cu) and zinc (Zn), as both are essential for normal metabolism but toxic in high concentrations. Increasing levels of these two metals in the body will be toxic and may damage and malfunction human organs[Getaneh and Alemayehu, 2006, Thornton, 1996]. Different parts of the world have documented and reported case histories related to health effects due to excess heavy metal concentration exposure[Ashley and Lottermoser, 1999, Ogola et al., 2002, Miller et al., 2004, Von der Heyden and New, 2004, El-Moselhy and Gabal, 2004]. Exposure to heavy metals like arsenic, lead, and cadmium are

known to cause neural and metabolic disorders, cancers and other diseases[Thornton, 1996, Patel et al., 2005, Appleton et al., 1996]. Lead is another metal of great concern as it can cause brain, liver and kidney damage in children and nerve damage in adults, while long term exposure to cadmium can cause kidney failure, liver, bone and blood damage.

Table 2.1: Total number of towns and cities in AAP database, 2016 version, by region

<i>Region</i>	<i>Number of towns/cities</i>	<i>Number of countries with data</i>	<i>Total number of countries in region</i>
<i>Africa (Sub-Saharan) (LMIC)</i>	39	10	47
<i>Americas (LMIC)</i>	102	13	24
<i>Americas (HIC)</i>	524	6	11
<i>Eastern Mediterranean (LMIC)</i>	53	8	15
<i>Eastern Mediterranean (HIC)</i>	31	6	6
<i>Europe (LMIC)</i>	165	9	19
<i>Europe (HIC)</i>	1 549	33	34
<i>South-East Asia (LMIC)</i>	175	9	11
<i>Western Pacific (LMIC)</i>	225	4	21
<i>Western Pacific (HIC)</i>	109	5	6
<i>Global</i>	<i>2 972</i>	<i>103</i>	<i>194</i>

AAP: Ambient air pollution database; LMIC: Low-and middle-income countries ; HIC: high-income countries.

Source: [WHO, 2016a]

Mercury is a by-product of gold extraction. A few drops of metallic mercury can raise air concentration of mercury to harmful levels[ATSDR, 2015b]. The risk to health is greater when there is longer exposure[ATSDR, 2015b]. One can be exposed to metallic mercury vapors from breathing contaminated air around hazardous waste sites, power plants that burn mercury-containing fuels, or waste incinerators[ATSDR, 2015b]. A major source for elemental mercury is through inhalation in occupational settings[EPA, 2016b]. The presence of mercury in the gold mining industry is a risk to both the workers and the nearby communities. Elemental (metallic) mercury is one of the anthropogenic inadvertent by-product of gold mining.(WHO2008a) The retort heating of precipitates from electrowinning process serves a purpose for the removal or residual mercury. The containment of mercury in this process is vital to avoid leakages and spillage to the environment. Health effects caused by short-term exposure to high levels of mercury include: cough, sore throat; shortness of breath; chest pain; nausea, vomiting diarrhea; increase in blood pressure or heart rate; a metallic taste in the mouth; eye irritation; headache; and vision problems[ATSDR, 2015a, ATSDR, 2015b][ATSDR, 2015b]. Health effects caused by long-term exposure to mercury vapors include: anxiety; excessive shyness; anorexia; sleeping problems; loss of appetite; irritability; fatigue; forgetfulness; tremors; changes in vision; and changes in hearing[ATSDR, 2015a]. Even though the major systems impacted by human inhalation of elemental mercury are the kidneys and central nervous systems (CNS), gastrointestinal and respiratory effects, such as chest pains, dyspnea, cough, pulmonary function impairment, and interstitial pneumonitis have also been noted from human inhalation exposure to elemental mercury[EPA, 2016b]. Mercury can be detected in blood, urine, and hair samples through

laboratory tests[EPA, 2016b].

1.4 Burden of air pollution

Ambient air pollution in 2012 was estimated to have caused 3.7 million deaths globally [WHO, 2014]. The LMICs which represent 82% of the world population, had about 88% of these deaths[WHO, 2014]. A report from the World Bank and the Institute for Health Metrics and Evaluation (IHME) stated that air pollution, with the ability to cause lung cancer, heart disease and stroke, costs the global economy roughly \$225 billion in 2013[IHME, 2016]. It was also ranked as the fourth-leading risk factor for premature death in the same year according to the Global Burden of Disease Study 2013. The IHME and World Bank researchers' report found that more than 2.9 million deaths in 2013 were caused by ambient pollution, an increase of more 30% from 1990[IHME, 2016]. It caused 23.6% lung cancer deaths, 14.5% of stroke and 13.6% of ischemic heart disease deaths. Also according to this report, approximately 87% of the world's population resided in areas exceeding WHO air quality guidelines[IHME, 2016].

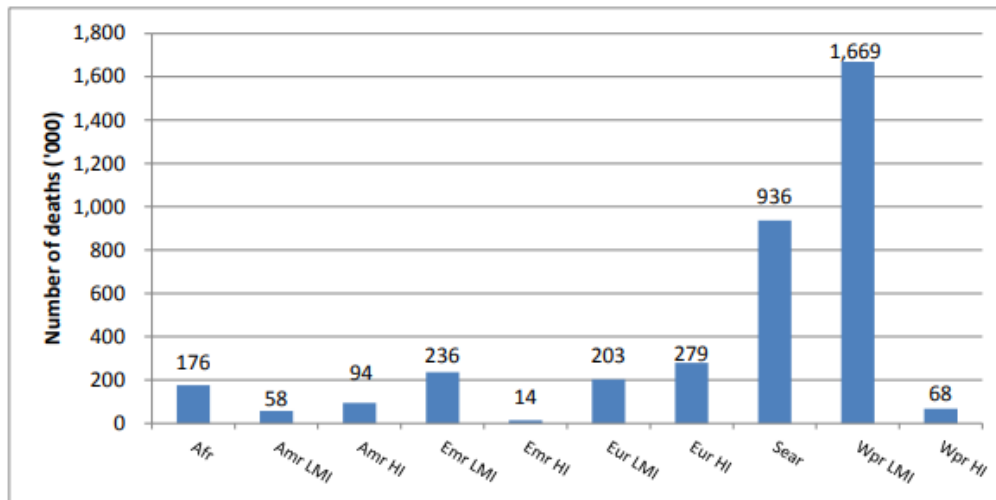
For indoor air pollution, the report stated that 42.2% of the world's population are exposed to air pollution from burning of solid fuels in homes [IHME, 2016]. It caused 2.9 million deaths in 2013 which was based from the estimates for LMICs. Similar to the risk of dying from ambient air pollution, indoor air pollution in 2013 contributed to a global 16.9% of lower respiratory infection deaths and roughly 21% of cataracts (a nonfatal outcome)[IHME, 2016].

Individuals have little control of the air we breath, and is one of the risk factors for premature deaths. It is an area that needs urgent attention and action as highlighted by the IHME director, Dr. Christopher J.L Murray[IHME, 2016]. The health loss from air pollution also has a significant economic cost. In 2013, the World Bank estimates that air pollution led to a \$225 billion in lost labor and \$55 trillion in welfare losses. The report quote "the economic costs associated with this elevated risk are a real drag on development". Premature deaths and illness caused by air pollution reduces the quality of life; while loss of productive labor result in less income, especially in developing countries where there is more household air pollution[IHME, 2016].

The burden of ambient air pollution were mostly felt by the Western Pacific and South East Asian regions with 1.67 million and 936000 deaths, respectively (Figure 2.1)[WHO, 2014]. Low- and middle-income countries in these two regions had the largest air pollution-related burden in 2012 with a total of 3.3 million deaths linked to indoor air pollution and 2.6 million deaths related to outdoor air pollution. Nearly 1,700 children under the age of five years died in the Pacific in 2016[Fund, 2018]. Deaths from ARI is a major concern in developing countries; however, a lack of community-based studies exist to document its aetiology and burden[Krishnan et al., 2015].

Acute lower respiratory infection was amongst the top 5 deaths related to AAP with ischaemic heart disease at the top of the list (Figure 2.2).

Since 2008, the burden estimate had almost tripled from 1.3 million deaths related to AAP [WHO, 2014] . Few factors had contributed to this increase including: "1) additional evidence that has become available on the relationship between exposure and health outcomes and the use of integrated exposure-response functions; 2) an increase in non-communicable diseases; 3) the inclusion of the rural population, whereas the previous estimate only covered the urban population; and 4) the use of a lower counterfactual, i.e. the baseline exposure against which the effect of air pollution is measured" [WHO, 2014].



AAP: Ambient air pollution; Amr: America, Afr: Africa; Emr: Eastern Mediterranean, Sear: South-East Asia, Wpr: Western Pacific; LMI: Low- and middle-income; HI: High-income.

Figure 2.1: Total deaths ('000) attributed to AAP in 2012, by region. *Source: WHO, 2014.*

1.5 Challenges to prediction of air pollution health impacts

The availability of air quality data is one of the main challenge face by low and middle income countries globally. In 2016, only four (4) countries of the 21 LMIC in the Western Pacific had ambient (outdoor) air quality data (Figure 2.1). The lack of air quality data limits the ability to recognize the health impacts of ambient air pollution. This creates fear of the unknown level of short-term and long-term health impacts the LMIC are facing. Countries with ambient air quality data are able to predict its likely health impacts. The risk of stroke, lung cancer, heart disease, and acute and chronic respiratory diseases, including asthma, for people living in urban areas with ambient air quality data increases as urban air quality declines [World Health Organization, 2018c]. The WHO has recognized a progress in the last two years as the AAP database has nearly doubled, with more cities measuring air pollution levels and recognizing the corresponding health impacts [World Health Organization, 2018c]. In the past two years, the database – now covering 3000 cities in 103 countries – has nearly doubled, with more cities measuring air pollution levels and identifying the associated health impacts [World Health Organization, 2018c].

2 Association between gold mining and air quality

Air pollutants generated from gold mining activities are threats to those working in the mines and the communities that reside within the proximity of the mine. Various activities and processes carried out within the mining industries generate high levels of air pollutants which are both harmful to the environment and human health. Potential emission sources on mines are complex, thereby hindering air quality management [Schwegler, 2006]. There is a wide range of source types, most are diffuse and highly changeable in nature, hard to measure, and site specific in relation to moisture content and silt. The climate factors such as temperature, humidity and

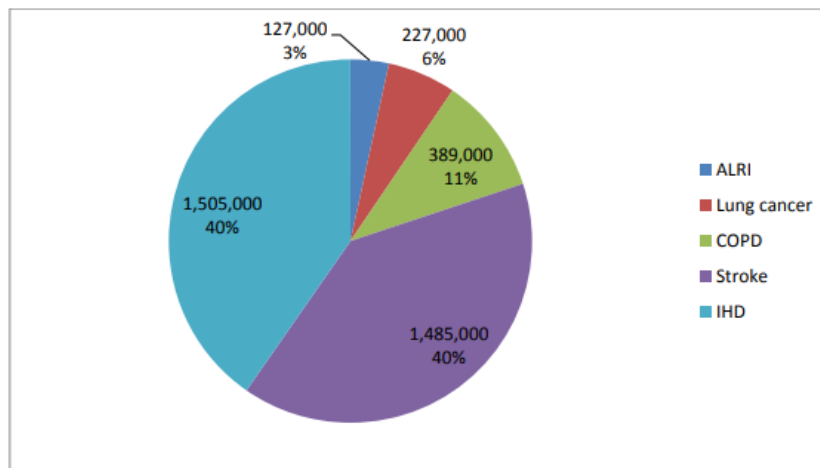


Figure 2.2: Deaths attributable to AAP in 2012, by disease[WHO, 2016a]

rainfall exacerbate emission uncertainties. Mines are subject to continuous changing footprint in relation to waste rock sizes, tailing sites, haul road distance and location, and have differing production and mine development rates.

Air pollution generated from underground drilling poses very high risks to the health of underground miners. The residential community near these mine will be exposed to air pollutants generated while the ore are transported from mouth of shafts to the ore processing facilities.

In large and medium gold mine, gold is extracted from the ore at the processing plant through cyanide leaching [Abdul-Wahab, Sabah and Marikar, Fouzul, 2012] method where cyanide solution is soaked into piles of crushed ore. The solubility of gold in a water and cyanide solution was discovered in 1783 by Cal Wilhelm Scheele, but it was not until the late 19th century, that an industrial process was developed[Wikipedia, 2017]. Even with the change of gold extraction process in China from amalgamation to cyanidation method in 1996, both processes led to different contamination results[Chen et al., 2017]. The overall extraction of gold from ore consists of the following stages: "crushing and grinding of the ore; addition of the process water to form slurry; addition of lime to the ore, and cyanide solution to the slurry, to leach the gold into solution; addition of carbon to adsorb dissolved metals and to remove them from the slurry; stripping the metals from the carbon by acid washing; and circulation of a caustic cyanide solution; precipitation of the gold by electro-winning; smelting of metal products into bars of dore bullion; pumping of the barren slurry (tailings) to the tailings storage facility"[Abdul-Wahab, Sabah and Marikar, Fouzul, 2012]. They summarize these processes into three steps: "grinding and size classification to reduce the ore down to a fine particle size; leaching and adsorption to extract the precious metals from the rock; recovery of gold to produce dore bullion bars". Figure 2.3 shows a detailed flow chart of a typical large-scale gold extraction processes. The Vatukoula Gold Mine gold also uses cyanidation for its gold extraction.

All of the stages in this gold extraction facility, including the transportation of ore to the plant, are highly likely to generate certain air pollutants. Delivery trucks are likely to generate dust apart from the commonly known vehicle emission air pollutants, while the extraction of gold in the treatment plant is likely to generate sulfur dioxide if elemental sulfur is used as the case in Vatukoula Gold Mine.

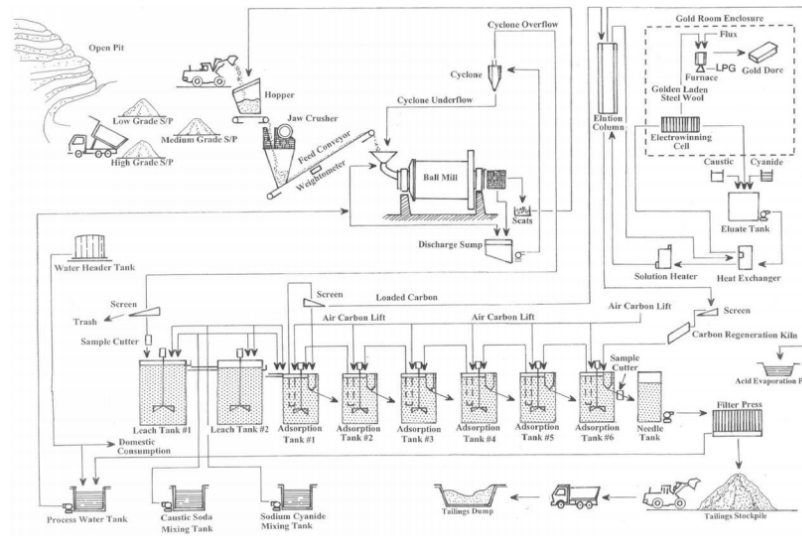


Figure 2.3: Gold Extraction Flow Chart (Source: *Abdul-Wahab & Marikar, 2011*)

The preparation of ore involves a number of steps from crushing and grinding of ore to the smelting of metal products into bars of dore bullion. All steps in the process flow chart (Figure 2.3) are highly likely to generate air pollutants. Residual gases which might include traces of heavy metals, are released to the environment from the cooling process (in a gravity-fed water) used to capture harmful gases during the ore roasting process.

2.1 Air pollutants generated from gold mining activities

Apart from the generation of criteria air pollutants, a gold mine is likely to produce excessive sulfur dioxide, dust, hydrogen cyanide and heavy metals, depending on the extraction method used. In mines, dust is mainly sourced from blasting, handling, processing or transporting of materials. Unpaved roads and open mine pits are sources of dust in gold mining areas. Trips made by all vehicles involved in gold mining on-surface operation are likely to generate a massive amount of emissions[Abdul-Wahab, Sabah and Marikar, Fouzul, 2012]. Wind erosion is likely to suspend dust from disturbed areas or waste disposal sites, including tailings and waste rock[Schwegler, 2006]. Large vehicles transporting extracted ores from the mine to the processing plant produce emissions and greenhouse gases just like any other combustion engine powered vehicle, but usually on a larger scale and with much lower fuel efficiency. Excessive sulphur dioxide is expected from the roaster stack[Ackley, 2008]. In Vatukoula, the crushed ore has a rich telluride composition which requires it to be roasted at high temperatures[Emberson-Bain, 2002]. This is a complicated process and VGM uses elemental sulfur for roasting resulting in release of more sulphur dioxide. The company now uses loose oil in the treatment plant to reduce the use of elemental sulfur (EO-VGM, personal communication, October 10, 2017). Sulphur dioxide emission has been the major air pollutant of concern amongst the Vatukoula residential communities located in close proximity to Fiji's main gold mine, Vatukoula Gold Mine[Ackley, 2008]. Studies have documented the presence of sulfur as a nuisance since the early days of the mine in the 1930s[Emberson-Bain, 2002]. This study quoted a diary entry of the District Commissioner

Central during his visit to the Loloma mine in 1938 as "very interesting but very dusty and fumes from furnaces unbearable, sulfur". This statement is still valid now after 80 years of operation of the mine, as dust and sulfur continue to pollute the mining facilities and all other residential areas in its vicinity. Schools located near this gold mine have to close all their windows from early as 8am until the early afternoon to avoid harmful emissions. Due to this fact, a number of teachers felt uncomfortable and requested for transfer out of this location[Ackley, 2008]. Two mining sites in Australia, Mt. Isa and Kalgoorlie, are two areas where high amount of sulphur dioxide in the air can occur and that happens only occasionally[DOE, 2005].

The mining and quarrying sector contribution to air pollution in Fiji is increasing. The data provided for the mining and quarrying sector shows that it is a sufficiently large source of emissions to be reported as a separate sub-sector. It is responsible for 5.7% of Fiji's energy use, and similarly for 5.9% of carbon dioxide emissions (91.75 Gg), which may rise if further activities are approved[Government of the Republic of Fiji, 2013].

Hydrogen cyanide

The use of cyanide for metal extraction from the 1700s was due to its ability to dissolve gold in water and is also a common industrial chemical that is readily available at a reasonably low cost. It is the chemical of choice for metal extraction in gold mines. Dilute solutions of sodium cyanide, typically in the range of 0.01% and 0.05% cyanide (100 to 500 parts per million) are used in the gold extraction process.[Mark J. Logsdon, 1999]. The cyanidation process of gold extraction result in the emission of hydrogen cyanide and production of huge amount of tailings, a potential source of heavy metals when the extraction involved low-grade ores[Fashola et al., 2016]. The cyanide leaching technique used in extracting gold is "particularly damaging to the environment, infringes the principle of sustainable development, consumes large quantities of water and energy, contributes to global warming, emits hydrogen cyanide and creates a morass of hazardous waste. Land, water, and air pollution are all a byproduct of gold mining through the cyanide heap-leaching method" [Abdul-Wahab, Sabah and Marikar, Fouzul, 2012].

Heavy metals

Apart from the criteria pollutants listed above, gold mining generates other harmful air pollutants including heavy metals. Gold mining activities contribute to the metal load of the environment[Getaneh and Alemayehu, 2006]. A wide variety of heavy metals are exposed during gold mining. Gold mining is one of the heavy industries that contaminate the environment with heavy metals. A study by Abdul-Wahab and Marikar on environmental impact of gold mine at a mine located in Wilayet Yanqol in Adaherh region of the Sultanate of Oman found the presence of some heavy metals namely iron (Fe), zinc (Zn), vanadium (V), aluminium (Al), manganese (Mn), nickel (Ni), chromium (Cr), lead (Pb), copper (Cu), and cadmium (Cd) in environmental media sampled[Abdul-Wahab, Sabah and Marikar, Fouzul, 2012]. Surface sediments from rivers, lakes, and streams from active gold mine districts in Ghana showed higher levels for lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), copper (Cu), and chromium (Cr)[Armah and Gyeabour, 2013]. Pb, Cu, Cr, and Hg concentrations were 3, 11, 12, and 16 times more than the sediment guideline values set in the Australian and New Zealand Environment and Conservation Council (ANZECC) [Armah and Gyeabour, 2013]. Wheat samples from gold mining contaminated soils had higher levels of Hg, Pb and Cd as compared to samples from a control site in a comparative study conducted in Xiaoqingling Mountains, China. These

are few examples of heavy metal from gold mining contaminating the environment that human depend on for survival.

The ultimate source of metals (As, Ni, Pb, Cu, etc) are from minerals, mainly sulfides in the ore aggregate[Getaneh and Alemayehu, 2006]. Apart from the normal geologic processes, the release of metals in the environment is facilitated by human activities relating to gold mining[Getaneh and Alemayehu, 2006]. Tailings dam is the most important sink for a number of metals[Getaneh and Alemayehu, 2006]. Dry sediments from tailings dispersed by strong wind can transport these metals to other locations impacting environment and human health. The tailings dam of the Legadambi primary gold mine is the most important sink for a number of metals.

Apart from natural sources, mining, metal smelting and burning of fossil fuels are the major industrial processes that contribute to arsenic contamination of air, water and soil[Green Facts, 2016]. The growing number of industrial factories in developing countries, especially in cities where vehicle and industrial emissions, and also household activities, create serious air pollution[Chung et al., 2014]. Arsenic exists predominantly attached to a particulate matter[Chung et al., 2014]. The presence of arsenic in airborne particulate matter is considered a risk for certain diseases[Chung et al., 2014]. Arsenic oxide and sulfur oxide are by-products of roasting gold from arsenic[Wan, 2014]. An Australian study by Rachael Martin et al.,(2013) found a correlation between soil arsenic level and toenail arsenic concentrations ($p < 0.001$) in children. Increase in time spent outside with increased frequency and with longer periods correlates with increased arsenic uptake ($p < 0.05$)

Mercury is also a by-product of gold mining. A heavy metal, mercury is naturally occurring and found in the environment and exists in several forms. These forms can be grouped in three headings: metallic mercury (also called elemental mercury), inorganic mercury, and organic mercury[ATSDR, 2015b]. Metallic mercury is the pure or elemental form of mercury (i.e., it does not combined with other elements)[ATSDR, 2015b]. A major source of exposure for elemental mercury is through inhalation in occupational settings[EPA, 2016b]. Inorganic mercury compounds (also called mercury salts) occur when mercury combines with elements such as chlorine, sulfur, or oxygen[ATSDR, 2015b]. The general population is usually not exposed to inorganic mercury compounds to any significant extent today, as most products containing these compounds have now been banned[EPA, 2016b]. Organic mercury or organomercurials occur when mercury combines with carbon[ATSDR, 2015b]. The most important organic mercury compound, in terms of human exposure, is methylmercury[EPA, 2016b]. The release of mercury to the environment from human activities is significantly higher than the natural release from normal breakdown of minerals in rocks and soil from exposure to wind and water, and from volcanic activities[ATSDR, 2015b]. The mercury level in soils on a hazardous waste site may be up to 200,000 times higher than natural levels. The preindustrial era atmospheric mercury levels were very very low and do not pose a health risk but, the levels have increased three to six times higher now in the United States due to the steady release of mercury through human activities[ATSDR, 2015b]. A large proportion (80%) of mercury released from human activities is elemental mercury released to the air through mining and smelting, and other major activities such as fossil fuel combustion, burning of municipal and medical wastes, production of cement, and from uncontrolled releases in factories that use mercury[ATSDR, 2015b]. The other 15% and 5% are released to the soil and water bodies respectively[ATSDR, 2015a]. In the mining industries, metallic and inorganic mercury enters the air from mining deposits of ores that contain mercury[ATSDR, 2015b]. Gold ore processing and production is a significant source of mercury emissions[EPA, 2016a]. The Environmental Protection Agency (EPA) categorize mercury as part of the seven pollutants known as persistent, bioaccumulative pollutants[EPA, 2016a]. The

seven pollutants are: mercury, alkylated lead compounds, polycyclic organic matter (POM), hexachlorobenzene, polychlorinated biphenyls (PCBs), 2,3,7,8- tetrachlorodibenzofurans (TCDF) and 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD)[EPA, 2016a].

Mercury in gas form is a health hazard. However, the vapor cannot be seen (colorless) and odorless[ATSDR, 2015a]. In air, the mercury vapor can be changed into other forms of mercury, and can be further transported to water or soil in rain or snow. Mercury vapor in rain enters the water system where it is converted to methyl-mercury by microorganisms. This methyl-mercury enters the food chain through fish and is a major health risk to those consuming fish from these polluted rivers. In the gold mining industry, the mercury present is not usually from the mercury amalgamation process that is no longer used by formal gold mining companies, but from mercury in the ore that has followed gold through the leaching and precipitation processes[Wikipedia, 2017]. Gold precipitates from electrowinning processes are usually heated in a retort to recover any mercury present, that would otherwise cause health and environmental problems due to its release (volatilization) during smelting[Wikipedia, 2017]. Mercury vapor is heavier than air [ATSDR, 2015a].

In the Newmont Gold Mines, mercury is not used to mine or extract gold, but is present as naturally occurring compounds in ore at several of its operations [Newmont, 2014]. In some of Newmont's gold-recovery processes, the heating of ore or ore concentrates at certain temperatures transform naturally occurring mercury mineral compounds into gaseous elemental mercury. The company captures this gaseous mercury from entering the environment by capturing it using the maximum achievable control technology (MACT) – as defined by the Nevada Mercury Control Program standard – and retires or stores the collected mercury, thereby removing it from circulation.

Gold mine tailings in Obuasi, Ghana have reported elevated levels of As. The high levels have been attributed to the richness of arsenopyrite (FeAsS) mineralization in the gold-bearing rocks [Fashola et al., 2016]. Arsenic in its inorganic form, As(III), predominantly found in mine tailings, has the highest toxicity level. The cyanidation process that leaches gold from the ore also leaches As into the environment [Fashola et al., 2016]. In reference to the Ghana experience, it is highly likely that the high levels of arsenic noted from samples of water along Nasivi river in Vatukoula are from the Vatukoula Gold Mine.

2.2 Possible air pollutants generated from Vatukoula Gold Mine

Underground and open pit mining are both used in Vatukoula[Mines, 2013]. However, underground mining will become predominant in the medium term[Mines, 2013]. Gold ores are transported from underground for processing on the surface. In this case, air pollutants are expected to arise from transportation process and across the gold extraction processes to the tailings disposal sites.

The VGM Air Quality Management Plan 2009 listed the following as potential gaseous emissions during the operation of the mine: ore processing at Vatukoula Treatment Plant (VTP) which contributed to ground level SO_2 concentrations historically in excess of WHO standards as a result of the roaster; elevated levels of arsenic and mercury in the stack emission from the roaster; and inhalable dust from activities at the assay lab, gold room, crusher and other parts of VTP; vehicle exhaust; drilling, blasting and excavation; ore crushing and handling; open pit rehabilitation operations; wind erosion of cleared surfaces, especially at TSFs; dust from operation of heavy vehicles; and exhaust gases from power plant. Dust from the five unused

(decommissioned) tailings dam are likely to contain high levels of air pollutants. The raising of Dakovono Dam which started in 2015 and continued when this study was conducted is another source of air pollution to the Vatukoula gold mining community. Trucks carrying loads of soil move daily from near the open cut mine through the gravel Haulage Road to the Dakovono dam on daily basis. Residential homes and a school located near this Haulage road are exposed to dust and vehicle exhaust fumes. During the focus group discussion, dust and fumes were confirmed as the main source of complain for those residing near this road. The participants also confirm the retailing of Slime Dam where loads of sediments from the Slime Dam are currently transported continuously through this same road by similar trucks for retailing at VTP. This further exaggerate the air quality issue. To address this, the environment officer of VGM informed that water is sprayed on Haulage Road and Dakovono Dam Road on daily basis to control dust. However, the FGD participants highlighted that even though water is sprayed, dust still reoccur when the water dries up while awaiting another trip of spraying. The spraying of water cannot mitigate against the vehicle emissions that are released to the atmosphere from these trucks.

Even though there was no study found that highlight ambient air quality status from the various pollution sources that exists within Vatukoula, community concern and environment medium have indicated the presence and impact of air pollutants. Ackley's risk perception and risk concern study found that the greatest concern among residents of Vatukoula was on the risk posed by air pollution, with 74.5% people feeling "very worried" with added to this was another 12.2% who felt "somewhat" worried. Water samples collected around the vicinity of Vatukoula, after the closure of the mine for eight months, also showed the presence mercury, nickel, cobalt, chromium zinc, and total cyanide; with no detection of copper, lead and cadmium[Ackley, 2008]. The analysis showed arsenic at level exceeding the maximum allowable WHO drinking water guideline standard. Local geology, chemicals used in gold mining processes, and their potential by-products were criteria used to select these parameters[Ackley, 2008]. These chemical concentrations are expected to be higher in a normal gold mining operating season. The risk of heavy metal and cyanide contamination during normal operating periods before the closer of mine was much higher than the current post-closure risk[Ackley, 2008]. Surface water samples collected eight months after the closure of Vatukoula Gold Mine on 5th December 2006 showed high levels of arsenic that exceeded the maximum allowable WHO drinking water guideline of 10 ppb[Ackley, 2008]. Community experiences on dust and sulfur dioxide over the years can explain the air quality status in Vatukoula. Section 2 of Chapter 4 describes in detail the experiences of community members on air pollution related to gold mining that they face throughout the years. Possible air pollution sources from Vatukoula Gold Mine are described. The section also described the activities undertaken by VGM to address air quality issues in Vatukoula and the roles played by other government departments.

3 Distribution and determinants of acute respiratory infections

3.1 Defining acute respiratory infection

Acute respiratory tract infections (ARIs) are classified as upper respiratory infections or lower respiratory tract infections[Simoes et al., 2006]. The upper respiratory tract comprised of the airways from the nostrils to the vocal cords in the larynx, and include the paranasal sinuses and the middle ear. The continuation of the airways from the trachea and bronchi down the

bronchioles and alveoli are regarded as the lower respiratory tract [Simoes et al., 2006]. Acute respiratory tract infections (ARIs) are heterogeneous and complex group of diseases caused by a wide range of pathogens in which the possible anatomic site(s) extend from the pharynx to the alveoli [Ujunwa and Ezeonu, 2014]. It is an acute infection of any part of the respiratory tract and related structures including paranasal sinuses, middle ear and pleural cavity [Baghel and Viswanadham, 2017]. Acute respiratory infection continues to be the leading cause of morbidity and mortality for children under 5 years [Walke et al., 2014]. A significant proportion of cases occur in developing countries [Berman, 1991] and are a major burden to child health [Mulholland, 2007, Liu et al., 2012]. The leading cause of death among children under five years in these countries are ARIs, mainly of lower respiratory tract [Campbell, 1995, Victora et al., 2005, Wardlaw et al., 2006]. Globally, a large percentage (85-88%) of ARI cases are acute upper respiratory infections (AURI) with the remaining being acute lower respiratory infections (ALRI) [Tambe et al., 1999, Jain et al., 2001]. Pneumonia, an ALRI, was a single most important killer for children under five years in India, responsible for almost 28 percent of all deaths [Collaborators, 2010]. However, generally, deaths from acute lower respiratory infection in children under 5 years has dropped significantly in the WHO East Asia and Pacific Region and also globally over the last one and half decades [WHO, 2016c]. These may be attributed to the increased coverage of immunization against certain infections such as pneumonia and measles. Figure 2.4 shows the diagram of infections affecting the upper respiratory tract (tonsillitis, pharyngitis, laryngitis, and tracheitis), and those affecting the lower respiratory tract (pleurisy, bronchiolitis, bronchitis, and pneumonia). In regards to air pollution impact on the respiratory, small particulate matter have the capability to penetrate deeper into the lower respiratory tract, causing infection to the lungs [EPA, 2017g].

Acute upper respiratory tract infection (AURI)

Acute upper respiratory infections (AURI) are the most common infectious diseases, and affect the upper respiratory tract (Figure 2.4 [Simoes et al., 2006]). They include rhinitis (common cold), acute pharyngitis or tonsillopharyngitis, ear infections, laryngitis, sinusitis, and epiglottitis - of which pharyngitis and ear infections cause the more severe complications (deafness and acute rheumatic fever, respectively) [Simoes et al., 2006]. Most of the AURIs have viral etiology: respiratory syncytial viruses (RSVs), human metapneumovirus, parainfluenza and influenza viruses, and adenoviruses account for 25 to 35 percent of AURI; rhinoviruses account for 25 to 30 percent; corona viruses for 10 percent; while the remainder taken up by unidentified viruses [Denny Jr, 1995, Simoes et al., 2006]. As most AURI are self-limiting, concerns are on their complications rather than the infections. Acute viral infections make children susceptible to bacterial infections of the sinuses and middle ear, and inhalation of infected secretions and cells can cause ALRI [Berman, 1995, Simoes et al., 2006].

Acute lower respiratory infection (pneumonia)

Pneumonia is a form of acute respiratory infection that affects the lungs, the lower part of the respiratory system. A person's lungs are made up of small air sacs called alveoli, that fill with air when the person breathes. However, in the case of pneumonia, the alveoli are filled with pus and fluid, making breathing painful and limits oxygen intake [World Health Organisation, 2016]. In children under 5 years of age, who have cough and/or difficult breathing, with or without fever, pneumonia is diagnosed by the presence of either fast breathing or lower chest wall in-drawing where their chest moves in or retracts during inhalation (in a healthy person, the

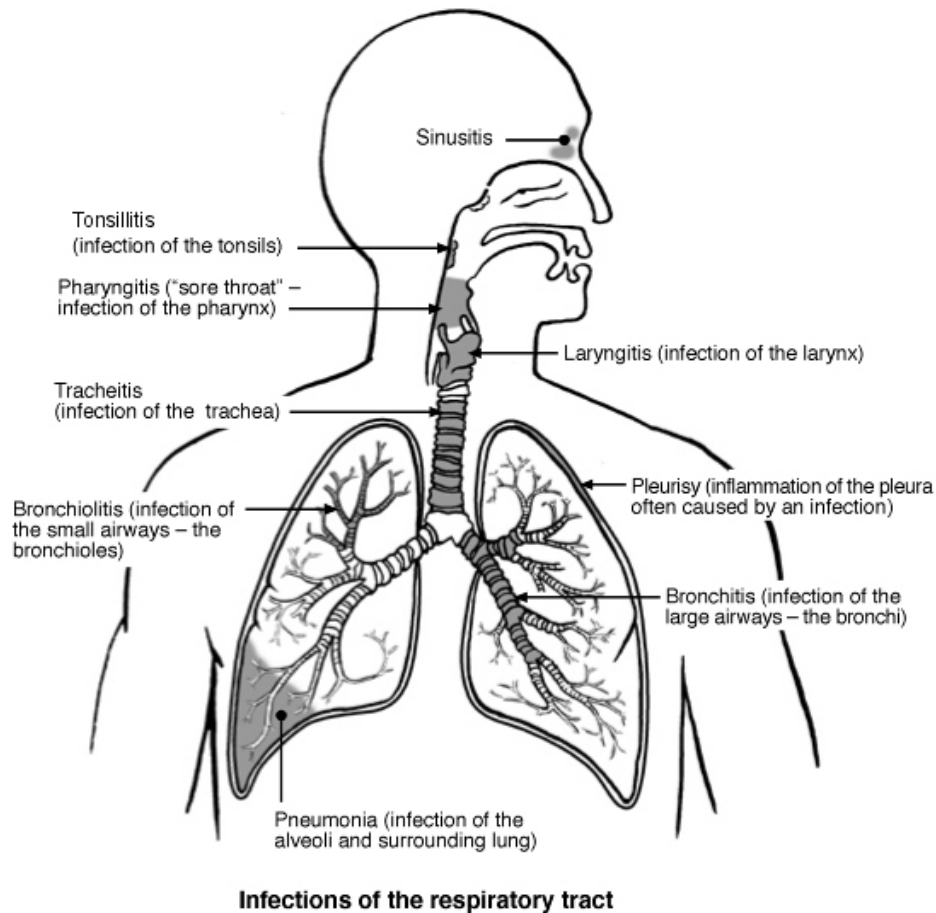


Figure 2.4: Infections of the respiratory tract [Patient, 2015]

chest expands during inhalation)[World Health Organisation, 2016]. The WHO estimated that 16% of all deaths of children under five years old, killing 920, 136 children in 2015 are due to pneumonia[World Health Organisation, 2016]. Pneumonia, an infection of the lungs can either be caused by either bacteria, viruses, or fungi[of Child et al., 2005, Simoes et al., 2006, WHO, 2016b].

The etiology and clinical manifestations of pneumonia are different between children under 2 months of age and those older[WHO, 1991]. Fast breathing is a sensitive and specific indicator that is now used to identify pneumonia among children who are coughing or and having difficulty in breathing[WHO, 1991]. In the WHO IMCI Chart-booklet used in Fiji, a 2month to 12 month infant is classified as having pneumonia if the infant has 50 breaths per minute or more. Likewise, a 12month to five year child is classified as pneumonia if the child has 40 breaths per minute or more[of Child et al., 2005]. The lung become stiff when a child develop pneumonia. Fast breathing is the body's responses to stiff lungs and hypoxia (too little oxygen)[of Child et al., 2005]. Chest in-drawing is a sign of severe pneumonia and may occur due to the lungs getting stiffer[of Child et al., 2005]. A pneumonia for an infants less than 2 months

of age is classified when the infant has a respiratory rate of 60 per minute or above (confirmed by a second reading), or when there is a marked chest in-drawing[WHO, 1991]. Young infants can become sick and die very quickly from pneumonia; therefore any young infant who has a sign of pneumonia is classified as severe pneumonia for quick referral and treatment. However, fast breathing and marked chest in-drawing are not sensitive enough to detect pneumonia in young infants. Therefore, certain non-specific signs have also been used to detect pneumonia which includes: the infant stops feeding well, is abnormally sleepy or difficult to wake, has fever or hypothermia (body temperature <35.5 deg.celcius), or has convulsions[WHO, 1991].

Bacterial pneumonia can be caused by streptococcus pneumoniae (pneumococcus) or Haemophilus influenzae, mostly type b (Hib), and occasionally by staphylococcus aureus or other streptococci [Simoes et al., 2006, World Health Organisation, 2016]. Streptococcus pneumoniae is the most common cause of bacterial infection in children followed by Haemophilus influenzae type b (Hib)[WHO, 2016b]. Most cases of bacterial pneumonia are caused by 8 to 12 types of pneumococcus, even though the specific type may differ between children and adults and between geographic locations[Simoes et al., 2006]. Mycoplasma pneumoniae and chlamydia pneumoniae are other pathogens that atypical pneumonia[Kramer et al., 2001]. A review of several studies by Vuori-Holopainen and Peltola (2001) indicated that 13 to 34 percent and 1.4 to 42.0 percent of bacterial pneumonia were caused S.pneumoniae and Hib, respectively while other studies suggests that Hib accounts for 5 to 11 percent of pneumonia[Vuori-Holopainen and Peltola, 2001]. Haemophilus influenzae type b (Hib) bacteria is responsible for severe pneumonia, meningitis and other invasive diseases almost predominantly in children under five years of age. The transmission of this bacteria is through the respiratory tract from infected to susceptible individuals.

Pneumonia can be transmitted in a number of ways. Bacteria and viruses found in child's nose or throat may affect the lungs when inhaled. Transmission may also occur through air-born droplets from a cough or sneeze. Blood transmission is also possible especially during or shortly after birth. However, the World Health Organization highlighted that more research needs to be done on the different pathogens that are causing pneumonia and how they are transmitted, which is vital for effective treatment and prevention[WHO, 2016b].

The inhalation of nasopharyngeal secretions into the lungs often lead to pneumonia[WHO, 1991]. Aspirations of these secretions is common to individuals, particularly during sleep. The pneumococcus and H.influenza are part of the normal flora of the upper respiratory tract. [WHO, 1991]. Potential pathogens that accumulating in the upper respiratory tract may enter the lungs during aspiration and could cause pneumonia if the local defense of the lower respiratory tract are impaired because of viral infection, malnutrition or other factors[WHO, 1991]. Studies have shown that the acquisition of S.pneumoniae and H.influenza in the upper respiratory tract occurs earlier in life and is more common in infants and young children in developing countries as compared to developed countries[WHO, 1991]. In a comparison study reported by WHO, the nasopharyngeal rate of *S.pneumoniae* is more than double while the *H.influenza type b* is six times more in developing countries than in developed countries[WHO, 1991].

Children with compromised immune systems are at higher risk of developing pneumonia as compared to those who are healthy with their natural defense system fighting off the infection[WHO, 2016b]. Malnutrition and undernourishment, especially in infants who are not exclusively breastfed, weaken a child's immune system[WHO, 2016b]. Further to this, pre-existing illnesses such as symptomatic HIV infection and measles, increases a child's risk of contracting pneumonia[WHO, 2016b].

The colonisation of upper respiratory tract with potentially pathogenic organisms and the inhalation of the contaminated secretions were known to have been associated with the pathogenesis of

bacterial pneumonia in young children[Simoës et al., 2006] The infection of the upper respiratory tract with influenza virus or RSVs is a predisposing factor for pneumonia. Studies have shown that the binding of both *H. influenzae* and *S. pneumoniae* to the lining cells in the nasopharynx increased when the respiratory tract is infected with influenza virus or respiratory syncytial virus (RSV)[Jiang et al., 1999, Hament et al., 2004, McCullers and Bartmess, 2003]. This may be the reason for increasing pneumococcal pneumonia rates during influenza and RSV epidemics[Simoës et al., 2006].

Viruses accounts for 40 to 50 percent for pneumonia hospitalization of infants and children in developing countries[Hortal et al., 1990, John et al., 1991, Tupasi et al., 1990, Simoës et al., 2006]. The most important causes of viral pneumonia are respiratory syncytial virus, parainfluenza viruses, influenza type A virus, measles virus, and adenoviruses[WHO, 2016b]. Radiographic differentiation of bacterial and viral pneumonias is difficult partly because the lesions appear similar as well as bacterial superinfection happen with influenza, RSV infections and measles[Ghafoor et al., 1990]. In developing countries, the viral pneumonia case fatality rate in children lie between 1.0 to 7.3 percent,[John et al., 1991, Stensballe et al., 2003] bacterial pneumonia at a range of 10 to 14 percent, while mixed viral and bacterial infections at a range of 16 to 18 percent[Ghafoor et al., 1990, Shann, 1986, Simoës et al., 2006]. The *Pneumocystis jiroveci*, a yeast-like fungus, is the most common cause of pneumonia for infants infected with HIV, and is responsible for almost a quarter of all pneumonia deaths in HIV-infected infants[WHO, 2016b].

Rapid identification of the causative agent is vital for its management. The spectrum of etiological agents is wider in paediatrics than in adult pneumonia[WHO, 1991]. Only in minority of cases do distinctive clinical features suggest a particular pathogen. Empirical antimicrobial therapy for pneumonia is the commonly accepted practice worldwide due to the diagnostic problems of this disease. Even in developed countries, paediatricians treat all those children with pneumonia with antimicrobials because it is impossible to exclude the presence of bacterial infection[WHO, 1991]. Poor management of acute respiratory infection can lead to complications. Typical cases are a complication of ear infections leading to deafness; and pharyngitis complications leading to rheumatic fever which can further develop into rheumatic heart disease, one of the serious diseases in developing countries[Simoës et al., 2006]. These are challenges faced by developing countries. Therefore, understanding and addressing ARI risk factors, and proper management of ARIs in children should be an area of importance to public health.

3.2 Distribution of acute respiratory tract infection

ARI globally

In 2015, the global under-five mortality was 43 per 1000 live births, a 44% decline as compared to the rates in 2000 [World Health Organization, 2017c]. Newborn deaths were about half of all under-five deaths in all WHO regions, except for WHO African Region where a third of under-five deaths happened after the first month of life[World Health Organization, 2017c]. The global under-five mortality rate in 2015 was 43 per 1000 live births, while the neonatal mortality rate was 19 per 1000 live births – representing declines of 44% and 37% respectively compared to the rates in 2000. Estimates also indicate that 30–50% of outpatient department (OPD) attendance and 20–40% of hospital admissions may be attributed to ARI and pneumonia[Walke et al., 2014].

Acute respiratory infection in developing countries

In the developing world, acute respiratory infections represent the major causes of mortality and morbidity among children under five years [Ujunwa and Ezeonu, 2014]. Pneumonia is often due to bacteria in developing countries. It is the single largest infectious cause of death in children worldwide and was responsible for 16%(920 136) of all deaths of children under five years old in 2015 [WHO, 2016b]. It affects children and families everywhere, but is most prevalent in South Asia and sub-Saharan Africa [WHO, 2016b]. The most common are *Streptococcus pneumoniae* and *Hemophilus influenzae*. Studies have shown that the acquisition of *S.pneumoniae* and *H.influenza* in the upper respiratory tract occurs earlier in life and is more common in infants and young children in developing countries as compared to developed countries [WHO, 1991]. In a comparison study reported by WHO, the nasopharyngeal rate of *S.pneumoniae* is more than double while the *H.influenza type b* is six times more in developing countries than in developed countries [WHO, 1991]. The situation used to be similar during the pre-antibiotic era, but has significantly decrease in developed countries after the introduction of antibiotics. Most episodes of pneumonia in developed countries now are of viral origins, the most common and important being respiratory syncytial virus, influenza, para-influenza and adenovirus [WHO, 1991]. Children with bacterial pneumonia may die from hypoxia (too little oxygen) or sepsis (generalized infection) [of Child et al., 2005]. The poor environmental and nutritional conditions prevalent in developing countries put children at higher risks as compared to other age groups [Romieu et al., 2002].

Acute respiratory infection in children

Children under five years are high risk group and vulnerable to respiratory infection as this is the developmental stage of their physical growth and lung function [Liu et al., 2013]. Their respiratory system is not completely developed until the age of six. Compared to adults, children breath more air in proportion to their body weights. The incidence of ARI in children for the first five years of life is about 6-8 episodes [Ujunwa and Ezeonu, 2014, Oyejide and Osinusi, 1991] Pneumonia and diarrhea top the list of infectious diseases which claim the lives of millions of children under-five globally, accounting for 16% and 8% of deaths, respectively [World Health Organization, 2017]. ARI is one priority area of intervention for the WHO and other international agencies [Garenne et al., 1992]. The burden of ARI in children under five years is high in developing countries. In 1990, the WHO estimated that out of the nearly 12.9 million from developing countries who die in each year, approximately 4.3 million die from ARI [Garenne et al., 1992]. Approximately one out of six deaths in developing countries for children aged 0-4 years are due to pneumonia [Garenne et al., 1992]. In 2015, a significant reduction was noted. Global under-five mortality has dropped from 91 deaths per 1000 live births in 1990 to 43 in 2015 [World Health Organisation, 2017]. The introduction of new vaccines such as Hib and pneumococcal is one of the main contributing factor to this global progress. However, despite this progress, the WHO recognises that there are countries that will be unable to meet their sustainable development goals of 25 deaths per 1000 live births by 2030 if they continue with their current approach in reducing under-five mortality [World Health Organisation, 2017].

Children under five years are more susceptible to substantial exposure to environmental pollutants than adults. This is because they breathe in more air, eat more food and drink more water per kilogram body weight as compared to adult [Armah et al., 2012, ATSDR, 1998, Sexton et al., 1992, Materia and Baglio, 2005]. They are also active and exercise more frequently than adults who increase their breathing rate, therefore, increasing the volume of pollutants to enter their respi-

ratory system[ATSDR, 1998]. A study indicated that the vulnerability to breathing specific air pollutants depends on a person's respiratory health, and not his or her age[ATSDR, 1998]. Also, they may be more susceptible to some environmental pollutants depending on the phase of development at the time of exposure[Landrigan et al., 2004, Louis et al., 2006]. Evidence showed that exposure to arsenic in early life, both in gestation and early childhood, likely to increase mortality in young adults[ATSDR, 2007]. Accessing good health through right environmental conditions is vital for their growth and development.

The prevalence of nasopharyngeal carriage of pneumococci varies according to geographical locations. A study conducted in Fiji by Russel et al., (2006)[Russell et al., 2006] found 44.3% carriage rate in young children. Gratten et al., (1986)[Gratten et al., 1986] found a 100% carriage rate for children in Papua New Guinea, while France on the other hand had a low carriage rate of only 5.7%[Guillemot et al., 1998].

Acute respiratory tract infection in Fiji

Fiji's Ministry of Health Annual Report 2015 reported ARI as the main cause of morbidity in its population. It remained at the top of the list of notifiable diseases in the last decade[Ministry of Health, 2016]. Also in the last decade, the disease of the respiratory system was within the ten top cause of morbidity and was either first, second or third on the list[Ministry of Health, 2016]. On the top ten cause of mortality, chronic lower respiratory disease was between 6th and 8th place on the list during the same period.

The neonatal and infant mortality rate are low for Fiji [PIFS, 2012] as compared to other developing countries. A large reduction in child mortality rate from the year 2000[Ministry of Health, 2016]. Further to this, there is also a dramatic decrease in infant mortality rate from 20.76 deaths/1,000 live births in 2005 to a rate of 12.6 in 2015 (Figure 2.5). Various programs may have contributed to this success including vaccination, introduction of IMCI and improved maternal and child care programs over the years. The 2015 annual report of the MoHMS indicated pneumonia unspecified is the leading cause of admissions. Despite this, the report noted that the under five mortality rate has decreased significantly over the last five years with general improvement noted in immunisation status of one year olds.

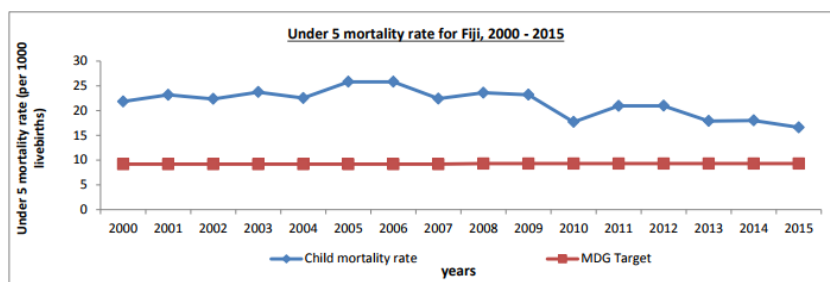


Figure 2.5: Under 5 Mortality Rate for Fiji 2000-2015 (Source: Ministry of Health Annual Report 2015)

Vaccination has been demonstrated as one of the most effective and cost-effective public health interventions[Ministry of Health and Medical Services, 2012]. Generally, over the years, Fiji has enjoyed strong coverage rate of more than 90% in its EPI programs that targets childhood up to primary school leaving age[Fong, 2016]. The MoHMS has seen significant improvement in the

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health of children under 5 years. A significant reduction in under 5 mortality rate occurred in the last decade with the rate of 25.81 deaths/1,000 live births in 2005 to a rate of 16.6 in 2015. The increasing availability and use of immunization for various childhood illnesses contributed to this success. The Extended Program on Immunization is an indicator to this success. The following immunizations are available locally for 0-1 year old: HBVO, BCG, DPT-HepB-Hib1, OPV1, Pneumococcal 1, Rotavirus 1, DPT-HepB-Hib2, OPV2, Pneumococcal 2, DPT-HepB-Hib3, OPV3, Pneumococcal 3, Rotavirus 2, and MRI [Ministry of Health, 2016]. According to Dr. Lisi Tikoduadua, the paediatrician with the Ministry of Health Fiji, vaccination played a significant role in saving the health of Fiji population [Alipate Vakamocea, 2017]. Measles which killed approximately a third of Fiji's population in 1875 was contained through vaccination; while polio is hardly seen in Fiji since 1962. All these progress are the result of immunization [Alipate Vakamocea, 2017].

A study on pneumococcal nasopharyngeal carriage rate in Fiji found that indigenous Fijian population had higher carriage rate [Russell et al., 2006]. The study found that having symptoms of acute respiratory infection and being indigenous Fijian were independent risk factors for carriage. The univariate analysis in this study noted exposure to indoor cooking smoke, child having low birth weight, having symptoms of ARI, and having two or more children under five years of age in the household as statistically significant risk factors of ARI [Russell et al., 2006]. The study highlighted domestic crowding to have contributed to productive cough in children [Flynn, 1994]. Acute respiratory infections (ARI) and diarrhoeal diseases remain the major causes of morbidity in young children in most developing countries of the Western Pacific region [WHO, 1995].

Acute respiratory tract infection management in Fiji

Fiji classify and manage ARI according to the WHO's IMCI classification and management guideline. The Integrated Management of Childhood Illness (IMCI) program was launched in the Pacific in 2001 [World Health Organization, 2009]. Now, more and more nurses in the district level in Fiji are equipped with this tool. A typical example is Balevuto Health Center which has a total of four nurses, and they have all undergone training in IMCI. Nurses treat respiratory infection cases in accordance with the IMCI guideline: severe pneumonia or very severe disease require antimicrobial treatment and immediate referral for inpatient care; pneumonia (non-severe) require antimicrobial treatment at home; and those with no pneumonia cough and cold are advised on home remedies. The staff nurse of Vunitogoloa Nursing Station stated the types of treatment for ARI in Fiji. When a child suffers from no 'pneumonia cough or cold', home remedy is usually advised by IMCI nurses. However, if child continue coughing for 5 days in a week, then the child has to be brought in to the nurse for review. If a child suffers from pneumonia, the case is treated by the IMCI nurse and is required for review after two days; and if the child suffers from severe pneumonia or severe disease, referral is made to the medical officer of the nearest hospital. (Akata, personal communication, November 10, 2017). The WHO grouped those non-pneumonia into four categories: wheezing disorders, bacterial upper respiratory infection (acute otitis media, suspected streptococcal pharyngitis), chronic cough, and simple coughs and colds [WHO, 1991].

The reporting of ARI is different from the public health facilities and from the hospitals. Dr. Evelyn, who currently leads the New Vaccine Evaluation Project in Fiji, highlighted the difference in reporting of cases experienced by the evaluation team that was collecting data for the project. The current reporting of ARI types mainly depend on the type of health facility. The public health facilities and even some outpatient generally classify and report all the three categories of respiratory illnesses in the IMCI booklet as ARI. ARI in these facilities can also be

a combination of pneumonia related and influenza when reported in the Notifiable Disease list. In some instances, the reporting of a case type can be according to the definition of the staff that attend to the case. A staff may report a case as ARI while another staff may specifically report the ARI type, whether its influenza or pneumonia. The hospitals report pneumonia specifically according to the case definition of the WHO Blue book. Dr. Evelyn stressed that even though the Communicable Disease Center (Mataika House) has the clear definition of ARI, more awareness is needed to correct this error of reporting in health facilities around the country. There is also a need to improve reporting of infectious disease in the country. Infectious disease data in the annual reports are in aggregate form with no stratification to highlight those at risk population such as children and elderly. There was only once in 2008 where the number of ARI for children under 5 years was reported.

3.3 Risk factors for acute respiratory infection

The risk factors for ARI are heterogeneous and complex. The prevalence of ARI is determined individually or collectively by various factors such as sociodemographic, socioeconomic, nutritional status, environment factors and so forth [Broor et al., 2001]. Those investigated in this study include the lack of breastfeeding, low birth weight, child's gender, child's ethnic background, and exposure to outdoor air quality.

Breastfeeding status

The WHO defines exclusive breastfeeding as the practice of only giving an infant breast-milk for the first six months of life [World Health Organization, 2018b]. Of all the preventative interventions, exclusive breastfeeding has the single largest potential impact on child mortality. Providing essential, irreplaceable nutrition for a child's growth and development, exclusive breastfeeding is therefore known as the cornerstone of child survival. It acts as the first immunization for a child and provides protection for diarrhoeal disease, respiratory infections, other likely life-threatening ailments; and also has a protective effects against obesity and non-communicable diseases later in life [World Health Organization, 2018b]. Despite its great importance to child growth and development, actual practice of exclusive breastfeeding is low. Only 38% of infants aged 0 to 6 months are exclusively breastfed globally. The WHO reported that in 2011, 11.6% (about 804 000) of mortality in children under five years of age were due to sub optimal breastfeeding practices, that include non-exclusive breastfeeding.

Exclusive breastfeeding for the first six months of life is important for the child to achieve optimal growth, development and health [WHO, 2015]. The WHO stated that breast milk is the food for the healthy growth and development of infants [WHO, 2015]. A large cluster-randomized trial of breastfeeding promotion, PROBIT, based on the WHO baby-friendly hospital initiative in Belarus, found breastfeeding likely to enhance the antibody response to pneumonia causing pathogens e.g. *Haemophilus influenza*, *pneumococci*), with the trial showing 15% reduction in respiratory-disease-related hospitalization [Kramer et al., 2001]. However, in this study, breastfeeding had more significant association with diarrhoea risk reduction than ALRI. The findings from this study on the benefits of breastfeeding promotion on ALRI morbidity was in line with other accepted health benefits of breastfeeding [Kramer et al., 2001]. Previous studies have noted that not exclusively breastfeeding infants was one of the main risk factor for ARI [Dharmage et al., 1996, Lepage et al., 1981, Victora et al., 1987, Chandra, 1979, Mitra, 2001, Broor et al., 2001, Acharya et al., 2003, Savitha et al., 2007, Ujunwa and Ezeonu, 2014].

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Previous studies have also found non-exclusive breastfeeding as a significant risk factor for pneumonia. A systematic review of 19 studies that investigated 19 risk factors of acute lower respiratory tract infection found the lack of exclusive breastfeeding (OR 2.34, 95%CI: 1.42 - 3.88) as one of the seven risk factors that were significantly associated with severe acute lower respiratory tract infection [Jackson et al., 2013]. A longitudinal study on ARI among rural under-fives in the Hooghly district (one of the districts of the state of West Bengal in India) non-exclusive breastfeeding was associated with an increasing number of ARI episodes [Mitra, 2001]. A case-control study conducted to identify the determinants of acute lower-respiratory-tract infection amongst children under five years old in the Children's Hospital in Colombo, found that not being exclusively breastfed up to the completion of four months increases the risk of ALRI in the multivariable analysis [Dharmage et al., 1996]. Breastfed infants in a rural community in India had a slightly lower incidence of respiratory infection, otitis, and pneumonia [Chandra, 1979]. Non-exclusive breastfeeding also increases the risk of infant mortality. In a study on specific mortality relative to breastfed infants in Brazil, infants that received artificial milk and those that were non-breast fed had higher risks of mortality, 1.6 and 3.6 respectively. [Victora et al., 1987].

Low birth weight

Low birth weight is defined by the WHO as weight at birth less than 2500g [WHO, 2018b]. It is associated with a range of both short- and long term consequences, and continues to be a significant health problem globally [WHO, 2018b]. The WHO estimated that more than 20 million births a year are of low birth weight, which is approximately 15% to 20% of all birth worldwide. Studies have shown that children with low birth weight are at higher risk of getting acute lower respiratory infection than those with normal birth weight [Dharmage et al., 1996, Harlap and Davies, 1974, Mitra, 2001]. Malnutrition and low birth weight are two relatively common risk factors for pneumonia in developing countries [WHO, 1991].

Ethnicity

Past studies in Fiji have indicated the risk of pneumonia to be high for I-taukei children. Magree et al. (2005) in their study on children less than five years to find the incidence and document the clinical features of chest X-ray- (CXR-) confirmed pneumonia found that the rate of presenting with lower respiratory tract infection as 2.5 times higher for Melanesian Fijians (I-taukei), and higher likelihood (29 times) of presenting with CXR-confirmed pneumonia [Magree et al., 2005]. Flynn (1994), in a cross-sectional study of rural children, found more productive coughs on most mornings on Fijian (I-taukei) (35.8%) than Indo-Fijians (23.9%) [Flynn, 1994]. A study by Russel et al., (2006) found that from all the nasopharyngeal (NP) swabs positive with *S. pneumoniae*, Fijian (I-taukei) children had higher carriage rate than Indo-Fijian (RR:2.4), indicating that being indigenous Fijian as an independent risk factor for pneumococcal NP carriage [Russell et al., 2006]. The burden of respiratory infections on indigenous population was also noted in Fiji's neighbouring countries, New Zealand and Australia [Grant et al., 2001, Chang et al., 2009].

Gender

Males are more likely to have acute upper respiratory tract infection than females. Several studies have identified male children having higher risk of acute respiratory infections than female

children [Marbury et al., 1996, Dharmage et al., 1996, Leeder et al., 1976, Ramani et al., 2016, Chhabra et al., 1994, Monto et al., 1974, Bashour et al., 1994]. A longitudinal cohort study conducted on 400 children in Gulbarga to assess the morbidity pattern and determinants of ARI found a significantly higher susceptibility to ARI of boys than girls ($OR = 2.41 : 0.41$) [Ramani et al., 2016]. The likely reason highlighted by this study could be that boys spend more time outdoors than girls thereby increasing their risk of exposure. In a study of respiratory illness for residents of Tecumseh, Mich, America, males experienced more illnesses than females for children under three years (Monto 1974 acute). A community-based study in Syria on the epidemiology of ARI in children under five years also found male having higher incidence and prevalence of ARI [Bashour et al., 1994].

Deaths attributable to AAP in 2012 were more for male than female. Three percent of total deaths attributed to AAP in 2012 were children under 5 years of age. Higher proportions of males suffering from acute lower respiratory infections were found in past studies [Marbury et al., 1996, Dharmage et al., 1996, Leeder et al., 1976, Chhabra et al., 1993, Ramani et al., 2016, Monto et al., 1974, Bashour et al., 1994, Kumar and Kalosona, 2016, Krishnan et al., 2015].

Environmental factors

Environmental factors also increase a child's susceptibility to ARI: such as indoor air pollution caused by cooking and heating with biomass fuels (such as wood or dung); living in crowded homes; and parental smoking [WHO, 2016b]. Past studies have identified the numerous and complex risk factors of acute lower respiratory infections in children. In a case control study involving children admitted with ALRI in the Children's Hospital in Colombo found, after multivariate analysis, the following factors increased the risk of ALRI: history of wheezing, passive smoking, sharing of sleeping space, and having pets [Dharmage et al., 1996]. Studies have also shown the impact of outdoor air pollution on respiratory health. The WHO in 2014 estimated that outdoor air pollution from urban and rural sources contributed to an estimated 3.7 million deaths globally [World Health Organization, 2014]. Air pollution is a risk factor for respiratory infection in children [Romieu et al., 2002]. Exposure to air pollution increases the incidence of upper and lower-respiratory infections in children [Romieu et al., 2002]. A study conducted on children in 7 cities of Northeast China found that those living near a chimney or a factory had higher prevalence of respiratory systems [Liu et al., 2013]. Long-term exposure to air pollution as defined by PM10 concentrations, was associated with increased respiratory symptoms [Hoek et al., 2012].

There is high possibility that air pollution will significantly impair lung function [Longhini et al., 2004, Bernstein, 2012, Ma et al., 2008] lung, bernstein2012traffic, ma2008effects). Exposure to ambient particulate matter (PM2.5 and PM10) in four Chinese cities was associated with decreased development of lung function [Roy et al., 2012]. Proximity to air pollutant point source was statistically significantly associated with increasing respiratory symptoms in a study conducted in southwestern British Columbia [Clark et al., 2010]. A person's exposure status is determined by both the pollutant concentration in an environment and the time (person-time) spent in the environment [Smith and Mehta, 2003, Mishra, 2003, Kumar and Kalosona, 2016].

As expected, the developing countries face the biggest air-pollution related health burden [WHO, 2008]. The WHO recognizes the lack of knowledge on health impacts of air pollution as an obstacle in mobilizing actions to minimize this greatest environmental risk. Nevertheless, in 2016, the WHO observed a 50% increase in ambient air pollution ground measurement in LMICs [WHO, 2016a]. This shows an increased awareness of the risks caused by air pollution [WHO, 2016a].

Chapter 3

Population and Methods

1 Study and control site profile

1.1 Brief profile of Fiji

The Republic of Fiji is an island nation with a total land mass of 18,272 sq km and an estimated population of 884,887 people after the 2017 national census[Fiji Bureau of Statistics, 2018]. The country has more than 332 islands which are scattered over 1.3 million square kilometers of the South Pacific Ocean, lying between latitudes of 15 degrees and 22 degrees South and between longitude 175 degrees East and 178 degrees West[Government of the Republic of Fiji, 2013]. Approximately one-third of these islands are inhabited[Government of the Republic of Fiji, 2013]. There are two larger islands, Viti Levu which is Fiji's main island having the capital city and the main international airport, and Vanua Levu, up in the north. In total, these two islands comprise 87% of the total land area of the country. The study sites for this research are located in the western part of Fiji and the northern part of Viti Levu.

Fiji's population increased from 837,271 (2007) to 884,887 in the 2017 population census, an increase of 5%[Fiji Bureau of Statistics, 2018]. The average population growth was only 0.6% which was due to low birth rates and out-migration. The median age of its population is 27.5 years, indicating that half of the population is under the age of 27.5 years. Almost 70% of Fiji's population is under the age of 40 years. While the total population has more men (50.7%) than women (49.3%), the age group of above 60 years has more female, indicating greater female longevity[Fiji Bureau of Statistics, 2018]. As of 2017, more of Fiji's population live in urban areas, 494,252 (55.9%), than in rural areas, 390,635 (44.1%)[Fiji Bureau of Statistics, 2018]. The urban population had an increase of 16.3%(69,406) since 2007; the rural to urban migration and extension of town boundaries contributing to this increase. On the other hand, as expected, the rural population declined by 5.3%(21,790)[Fiji Bureau of Statistics, 2018]. The 2017 census did not accurately classify the Fijian population into the different ethnic background for some reason known to the government at that time. However, in the 2007 census, Indigenous Fijians and Indo-Fijians were the two major ethnic groups: Indigenous with a population of 475,739 (57%); Indo-Fijians with 313,798 (37%); with the rest of 6% (47,734)being of other minor races[Fiji Bureau of Statistics, 2018].

Fiji's climate generally categorized as an oceanic tropical marine climate and varies over differ-

ent timescales. The El Nino Southern Oscillation (ENSO) phenomenon that occurs every four years on average, the South Pacific Convergence Zone and the Trade Winds are the significant features that drive Fiji's climate [Government of the Republic of Fiji, 2013]. The country is subject to potentially catastrophic climatic events such as flooding, cyclones and multiple landslips that have a significant impact on the economy and the infrastructure. The first ever most intense tropical cyclone on record to land in the Southern Hemisphere struck Fiji on the 20th of February 2016 [Wikipedia, 2018]. This category 5 Cyclone Winston killed 44 and left approximately FJ\$2.98 billion (US\$1.4 billion) in damages to homes, schools and infrastructure on many islands [Wikipedia, 2018]. This cyclone was cited as the costliest tropical cyclone on record in the South Pacific basin [Wikipedia, 2018]. Recently in April 2018 two cyclones followed each other, Cyclone Josie and Cyclone Keni, both bringing with them massive rainfall that flooded most parts of the country. According to Professor Biman Prasad, a politician and leader of the National Federation Party, the level of flood damage brought by Cyclone Josie, is a lot worse than that of previous floods [Radio New Zealand, 2018b], and killing five people [Radio New Zealand, 2018b]. Similar floods were experienced in 2009 [reliefweb, 2009] and 2012 [Newshub, 2012]. The cyclone did not make landfall in Fiji but only brought damaging gale force winds to some southern and western islands. Cyclone Keni was a destructive category three cyclone that hit the southeastern part of Fiji. Both Cyclone Josie and Keni costs Fiji \$US3 million [Radio New Zealand, 2018a].

Fiji's health system is mainly publicly financed [Irava, 2015]. In 2012, general taxation funded 66% of total health expenditure [Irava, 2015]. The out-of-pocket expenditure is relatively low (at around 22% in 2012), and are largely incurred by people of higher income brackets of society which mostly reside in urban centers [Irava, 2015]. Public health facilities provide a majority of outpatients service and a vast majority of inpatients. These services are funded by the at little or no cost to the population [Irava, 2015]. Nursing stations and health centres deliver the primary health care services. From these public health facilities, cases needing further treatment are referred up to the three levels of hospitals ending in national referral hospitals, and even further to overseas for complicated cases [Adrienne Chattoe-Brown and Majid, 2016]. In 2016, MoHMS has a total of 98 Nursing Stations, 79 Health Centers, 17 Sub-divisional Hospitals, 3 Divisional Hospital, and 2 National Referral Hospitals [Adrienne Chattoe-Brown and Majid, 2016]. Policy-making, health system management, human resource management, and pharmaceutical supply are centralised with the Ministry of Health and Medical Services (MoHMS) [Adrienne Chattoe-Brown and Majid, 2016]. The administration of service delivery by the MoHMS is in line with the national government's system where it divides the country into four divisions (western, eastern, and northern) according to their geographical locations. The 2011 birth cohort for this study is from the four nursing zones located in the Western Division (Figure 3.1, the warmer and drier part of Fiji's main island, Viti Levu).

Fiji experiences the "triple burden of disease" like many other countries. These are the "unfinished business" of communicable disease and reproductive health; an increasingly severe burden of NCDs (specifically diabetes, hypertension and cancer); and emerging risks from diseases and environmental change [Adrienne Chattoe-Brown and Majid, 2016]. Some significant challenges faced by the country include: the inability to reach the 2015 Millennium Development Goal four (reduce child mortality) and five (reduce maternal mortality) respectively; high prevalence of obesity leading to diabetes and diabetes-related amputations; malnutrition and child stunting are issues in some communities which may be related to poverty and lack of understanding of infants' nutritional requirements; threat of emerging diseases like Ebola and avian influenza being brought in by international travelers; and impact of climate change which include increased diseases in affected areas, salt water inundation and the need to relocate some local health facilities to other locations [Adrienne Chattoe-Brown and Majid, 2016].

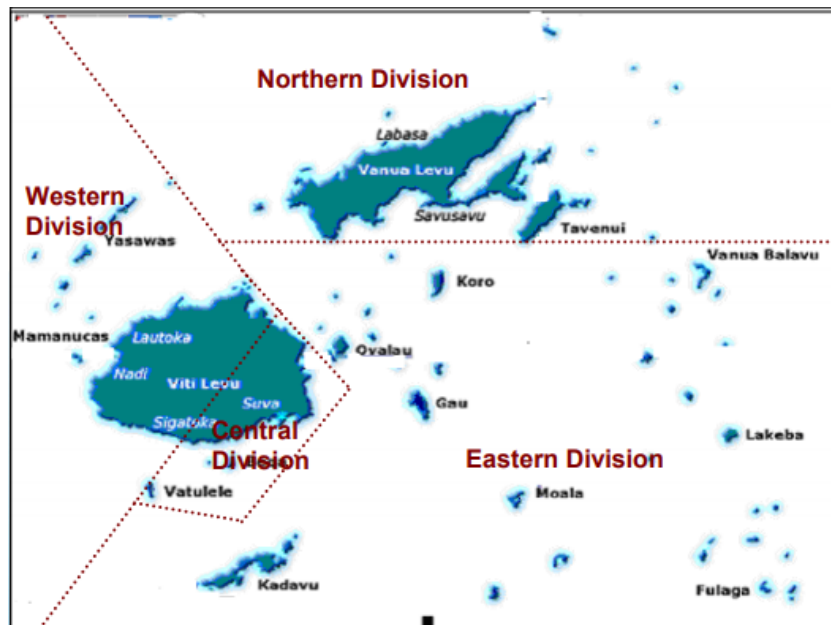


Figure 3.1: Western Division of Ministry of Health Fiji

Gold mining potential is enormous in Fiji as shown by the high number of exploration licenses issued and the various mining-related activities undertaken by each sector. This is likely due to the abundance of mineral deposits around the country as indicated in Appendix 4. The exploration licenses have increased from 16 in 2007-2008 [Government of the Republic of Fiji, 2013] to 59 in 2017 with a total of 8 mining lease (SEO-DOE, personal communication, October 25, 2017). According to the SEO-MRD, interest in mining has picked up slowly in the last two years even though the industry is globally dictated with exploration depending on the volatile global market. Fiji's Prime Minister, Mr Voreqe Bainimarama, stated during the opening of the Nawailevu Bauxite Mine in Bua, on 13th May 2011, that mining has great potential to increase both the government revenue and its GDP [Fijian Government, 2011a]. He further stated that with best investors, revenue from mining could equal those of Fiji's traditional revenue sources, i.e., sugar, and tourism.

There is increasing demand for mineral deposits believed to be abundant locally. Exploration and mining interest, both land and water, have grown over the years since colonial days with more and more foreign investors lured and seeking entry into the country [of Lands and Resources, 2017]. The Vatukoula Gold Mine is currently the only active gold and silver mine for the last 75 years (SEO-DOE, personal communication, October 25, 2017). A new gold mine, Tuvatu Gold Mine received its 21 years surface Special Mining Lease in January 2016 and groundbreaking conducted on November, 2017. Apart from gold, bauxite and iron two other minerals currently sought. Abundant deposits of bauxite have been found in the highland of Vanua Levu, the second largest island of Fiji [of Lands and Resources, 2017]. Bauxite mining commenced in Bua, Vanua Levu, in 2010 by XINF A Aurum Exploration Fiji Ltd [Fiji Times Online, 2017]. Iron deposits were found in the outskirts of Ba Town, situated in the western part of Fiji.

Mining contributed positively to the national and local economies. Fiji has earned a total of \$50.6 million from bauxite mining since 2010. The MRD Director, Dr. Faga, said that the returns

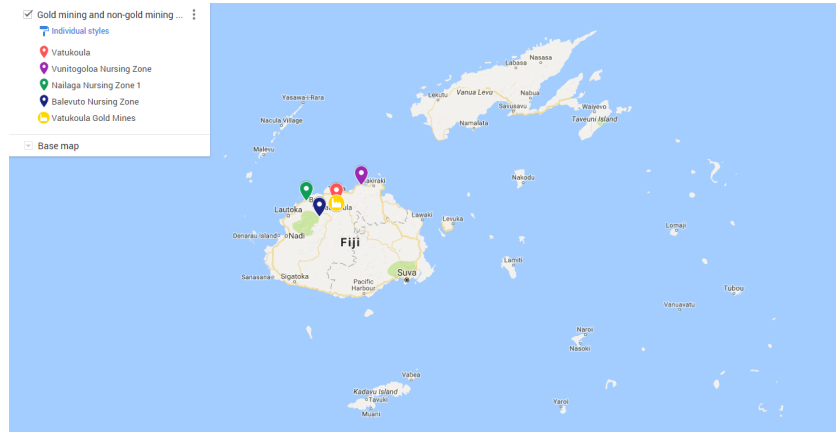


Figure 3.2: Map showing locations of nursing zones used as study sites, located in the western part of Fiji islands towards the northwest of the main island of Viti Levu. The Vatikoula Nursing Zone is the gold mining region while the rest of the three (Vunitogoloa, Balevuto and Nailaga Nursing Zones) are grouped as the non-gold mining region in this study

so far to the local population include compensation, employment, community project assistance and social assistance [Pacific Islands Report, 2017]. Further to this, the Acting Director for Mineral Resource Department, Apete Soro, indicated the increasing sites explored for deposits of minerals in Fiji. Considering the increase in mining interest, the department will ensure that the industry is environmentally sustainable. The director quoted "we are eager to exploit for minerals and MRD will ensure that the processes followed will not have a degrading effect on the environment" [of Lands and Resources, 2017].

1.2 Brief description of mining and non-mining regions

Profile of gold mining region

Vatikoula Nursing Zone

Vatikoula Nursing Zones is the mining region in this study due to its close location and association with the Vatikoula Gold Mine. Residential communities set within the gold mining lease of Vatikoula Gold Mine plc, the current operator of the mine. Even though there are specific names for the settlements that sit next to the mine, residents of this mining area are usually collectively known as residents of Vatikoula.

Vatikoula is located in the district of Tavua, in the province of Ba, in the western part of Fiji Islands, and in the northern part of Viti Levu (VGML2016) (refer to Figure). It is located approximately 10km inland from Tavua Town. Vatikoula is a public community throughout Fiji due to its close association with the gold mining since the 1930s.

The Vatikoula Gold Mine is the largest and longest producing gold mine in Fiji [Mine,]. Vatikoula Gold Mines plc. ("VGM" or "Group"), a United Kingdom (UK) public company, acquired the mine from its former owner in 2008. [Mines, 2013] The mine operates within three Special Mining Leases which cover a total of 1,255 hectares. apart from this, VGM has the right to explore areas outside the current mining leases via Special Prospecting Licenses that cover over

19,000 hectares of the surrounding Tavua volcano.[Mines, 2013] The mine has been operating for almost 80 years and has produced in excess of seven million ounces of gold.[Mine,]. The producing gold mine currently contains 4.1 million ounces of Mineral Resources and 750,000 ounces of Mineral Reserves.[Mine,]. Currently, both underground and open-pit mining are in operation. This was confirmed by the Environment Officer of VGM, a key informant in this study, further highlighting that sulfide is taken from underground while oxide (copper and gold) material are obtained from open cut. However, underground mining will become predominant in the medium term. [Mine,]There are four mining areas within Vatukoula where underground production are sourced from: Smith Shaft, Philip Shaft, R1 Cayzer Shaft and Emperor Decline. Three of these shafts are used to access underground workings for personnel and materials, and also for ore and waste haulage. The extraction of gold from the ore is carried out at the on-site Vatukoula Treatment Plant (VTP).[Mines, 2013] Gold Dore produced at the mine is typically 80% gold, 19% silver and 1% base metal such as copper and iron.[Mines, 2013] VGM sells the gold more to Perth Mint in Australia.[Mines, 2013] The overall aim of the company is to increase production to a sustainable and profitable level.

The residents of Vatukoula are from all the 14 provinces in Fiji (FGP1, focus group discussion, October 27, 2017). Since its beginning in the 1930s, I-taukei (formerly Fijians) continue to be the majority race in the Vatukoula Gold Mine,[Embersen-Bain, 2002] although the proportion of Indo-Fijian workers is increasing over the years. These I-taukei populations are mainly occupying the residential communities within the VGM mining lease (Tarau, personal communication, December 13, 2017). Children for this study were the ones born and raised in the Vatukoula Zone as according to the Tavua Medical Area zoning. The population of this Vatukoula zone is approximately 5,926. This zone has 6 settlements (Lomalagi, Korowere, Loloma, Matanagata, Lololevu, Lowcost) (FGP1, focus group discussion, October 27, 2017) which are located within the mining lease and mainly occupied by I-taukei communities and four settlements (Nasomo, Nasivi, Masimasi, Matanagata Back-road) located outside the mining lease, where Masimasi and Matanagata Back-road mainly occupied by Indo-Fijians who are mainly sugarcane farmers (Tarau, personal communication, December 13, 2017).

VGM mainly provides the necessary infrastructures in the mining lease. This includes electricity which is supplied by the 24 hours operating generators; roads around the mining areas; treated water carting from government supply to the communal water tanks, and supply of untreated water supply to communal standpipes for other domestic purposes; open space; and sporting facilities. Families have to fetch water from the communal tanks for drinking on a daily basis. However, mostly management staffs have the luxury of having individual drinking water tank at their homes. Water for other domestic purposes is piped from the Nasivi River to community standpipes. Some households have pipes connected to their homes. The company run its power plant 24hrs daily to provide power to the mine and the residential community. From 2009 to July 2017, 19 generators were running on diesel. However, nine new generators have been installed and are all running on HFO replacing all the diesel generators. However, areas without power include Lololevu, Lomalagi, Veiquwawa and Slime Dam. The three communication network (Telecom, Vodafone and Digicel) can all be accessed at the site.

Its close location to Tavua Town and the daily bus service make the people of Vatukoula more accessible to all the essential government services available in the town. Nevertheless, few services like Police and Post office are operating from Vatukoula. Health needs of all community members, except for staffs of VGM, are taken care of by the government at the Tavua Hospital and Tavua Health Center. Vatukoula Nursing Zone as mentioned earlier is divided into two nursing zones, Vatukoula Zone 1 and Vatukoula Zone 2, with a zone nurse allocated for each zone. Children

for this study are living in these two zones. Although more than 90% of the population are seen at the government hospital, this study found out that there is no surveillance system in place to report the diseases arising from Vatukoula residential community directly to the VGM management. The government has been carrying this load alone without the knowledge or action of the company who is the likely contributor to the environmental health-related conditions likely to affect human health. Staffs medical needs are handled by VGM's medical clinic operated by a Medical Officer and a staff nurse. VGM conducts garbage service on a weekly basis.

Most of those living in Vatukoula are working in the gold mine (FGP1, focus group discussion, October 27, 2016). Their families mainly rely on their income for the provision of daily needs. The economic viability of the Vatukoula community is heavily dependent on the mine since its establishment in the 1930s. Gold mining is now an intergenerational occupation for most of the families residing in Vatukoula. Few small retail shops are located around the Vatukoula residential communities. However, most do their shopping from Tavua Town and Tavua Market for fresh produce. Some homes have backyard gardens while some utilise the vacant spaces within the mining lease to plant root crops and vegetables. However, these vegetables are often affected by sulfur dioxide fall.

Education has been part of Vatukoula since those early days. A total of three primary schools, three kindergarten and one secondary school are located within the Vatukoula Nursing Zone. Except for one primary school, all other schools are located within the Vatukoula mining lease and close to the gold mine. The level of parental education is associated with acute respiratory infection as proven by some studies. In this study, the zone nurses were asked to describe the education level of mothers in their zones. In Vatukoula, most mother have secondary level education. According to the zone nurse, the mothers in this group are mostly proactive in the first year but after that some need continuous follow-up to bring their children for health check. It is always not easy to change a mother's attitude. Some seek traditional remedies before medical treatment when a child is sick. Attitude may contribute to negligence in taking appropriate care for a sick child. This result in late presentation of pneumonia to the health facility. However, overall, apart from mother that have attitude and are negligence, mothers in Vatukoula area look after their children well during our community visits. They bring their child with their food during their shift clinic. The zone nurse suspects that it is only the environment that they live in that is likely to contribute to their ill-health.

Housing issues has always been one of the center of discussion between those residing in company housing and the company. The houses in communities under mining lease belong to the company (CRO-VGM, Personal Communication, October 26, 2017). At one time, the houses belonging to the company were sold and most occupants bought the houses they live in, but without the land, as the land remained the property of VGM. Those families that have bought their homes have the responsibility to repair them (CRO-VGM, Personal Communication, October 26, 2017). If they move out of Vatukoula, they will have to dismantle their house or sell it back to the company as it is in the agreement. According to the CRO-VGM, the company will only repair houses that belong to it. Most of the houses occupied by employees and within the mining lease only have two rooms, one for dining and the other for sleeping (Tarau, Personal Communication, December 13, 2017). Participants of focus group discussion further stated that the houses owned by the company are not well maintained and are in deteriorating condition. Housing was one of the issues raised by Vatukoula Mineworkers to the management of the mine in the first ever Vatukoula Mine Workers struck in 1991. Poor housing together with alleged low wages, health concerns, unsafe working conditions, and weak environmental standards are items for protest against the management of the mine at that time (Macdonald, 2004). The FGD participants also

confirm that these houses have been existing even before they were born. Emberson-Bain (1994) explained that these houses were initially built in the 1930s primarily for single male miners. However, when families later moved in with the miners, little or no extra space was provided. Houses are mostly overcrowded as most families live with their extended family members, as is the case in most I-taukei families. The sanitation facilities for most communities within the mining lease are mainly communally shared where three to four households share a toilet and a bathroom. According to the CRO-VGM, the company has started with a plan to move away from that system and has encouraged each household to have their own sanitation facility.

Mine workers in Vatukoula have endured some of the most challenging times in the history of the mine until today. The longest ever strike is the Vatukoula miners' strike as they went on strike on February 1991 and are still on strike today at Vatukoula. Apart from the various work related and welfare related issues discussed earlier, a significant cause of the strike was the housing issue. Those on strike claim that they own the houses that they currently occupy, but, according to the Community Relation Officer, they did not buy it. Today they still declare themselves as strike workers and continue to attend their meetings (CRO-VGM, personal communication, October 24, 2017) even though the management of the mine has changed more than three times and have continued with its normal operations.

Profile of non-gold mining region

Vunitogoloa Nursing Zone

Vunitogoloa Nursing station is located in the district of Ra, Ra province, in the western part of Fiji Islands. It is located approximately 10km from Rakiraki Town, one of the rural towns in Fiji with its economic viability primarily depending on farming. Villages and settlements that are under the care of this nursing station are located along the Kings Highway between Rakiraki and Tavua. There are six villages and nine settlements in this nursing zone. It has a population of 3,364 comprising mainly of I-taukei, Indo-Fijian with very few belonging to other races.

The government provides few of the critical infrastructure. All communities in this nursing zone are accessible by roads and connected to power supply. The solar power supply is also introduced in the area due to its affordability. All mobile and telecommunication are made available by the three primary communication operators, Telecom, Vodafone and Digicel. The community themselves installs water supplies or assisted by the government or non-government organisations (NGOs) and the communities provide repair maintenance. All the communities are drinking from untreated water supplies with only approximately 2% drink from treated government supply.

The close location of this nursing area to the Kings Roads facilitate access to the government services available in Rakiraki Town. Few communities go to Tavua Town due to their proximity to this urban centre. The only essential government service located in this area is the Vunitogoloa Nursing Station while the rest are based in these two towns. The nursing station is managed by only one public health nurse, who is also trained in IMCI. The Vunitogoloa Nursing Station comes under Ra Medical Area where all referrals are made. However, as this area is located almost halfway between Rakiraki and Tavua, some of the residents find it easier to access services available in Tavua. People of this area travel to either Rakiraki Town/Rakiraki Market or Tavua Town/Tavua Market to purchase daily home needs. Transportation is not a problem for this area except for those living few kilometres inland that are not regularly serviced by bus. Small retails shops are also located in villages and settlements. Fresh vegetables are usually homegrown. Since this is a rural community, there is no garbage service, and each household is responsible for the

disposal of its household wastes. Burn bury and compost are the three common ways to manage waste in rural areas in Fiji.

The primary source of income for people in the Vunitogoloa Nursing area is through farming and fishing. Indo-Fijians are mainly commercial sugarcane farmers, with a few surviving on subsistence fishing, while some work as labourer in farms and nearby Town of Rakiraki and Tavua. For the I-taukei, some are sugarcane farmers while most survive on subsistence farming and fishing, with the rest working as a labourer as in the case of Indo-Fijians. In terms of mothers' education, most mothers in the Vunitogoloa Nursing Area are secondary school leavers. The Zone Nurse indicated that at one time, there was more primary school drop-out, but this is not the case now. The government policy that all children have to go to school is encouraging as it will raise the education level and knowledge of Fiji's citizen. Sending children to schools is not a burden anymore as all bus fares for children are paid by the government, except for those that have parents earning higher salaries. Five kindergarten schools, three primary schools and one secondary school are located within Vunitogoloa Nursing Zone. However, some children go out to schools outside this zone. Children either attend secondary schools in Rakiraki or Tavua.

Local carpenters usually build homes in villages and settlements. While some houses managed to overcome strong cyclone, like category 5 Cyclone Winston, many could not sustain such strong winds due to their weak structures. According to the nurse, Cyclone Winston came as a "blessing in disguise" as it allowed the change of housing from those old ones to the new ones that were funded by the government.

The Vunitogoloa Zone Nurse indicated that public health nurses had done their best to create awareness on child health (Akata, personal communication, November 10, 2017). However, they are mindful of some barriers outside their reach which are likely to hinder the improvement of childhood health. Some barriers include the mothers' education, breastfeeding, socio-economic issues, overcrowding and changing lifestyle. The nurse added that there is a perception among community members that those who buy from the supermarkets are well-off, even though we have much fresh produce in the market and farms. From her experience, the practice of breastfeeding is reducing while bottle feeding is increasing. Some factors affecting breastfeeding include "financial well-being, mothers' education level, and mothers' commitment leaving her no time to breastfed her child" (Akata, personal communication, November 10, 2017).

Nailaga Nursing Zone 1

Nailaga Nursing Zone 1 is one of the two nursing zones under Nailaga Health Centre, located in the district of Ba, Ba province, also in the western part of Fiji Islands. The Nailaga Medical Area is divided into two Nursing Zones, Nursing Zone 1 which is towards Lautoka, and Nursing Zone 2 which is towards Ba. Children who were retrospectively observed in this study were those from Nursing Zone 1. This zone is located almost mid-way between Ba Town and Lautoka City, approximately 10km from Ba along the Kings Highway. Villages and settlements under Nailaga Health Center are located along the Kings Highway, while the some are located few kilometers inland, and some towards the sea.

The Nailaga Health Center has a population of 11,187 (2417 I-taukei, 8738 Indo-Fijian and 32 other races) of which Nailaga Nursing Zone 1 consists of 6,139 (750 I-taukei, 5367 Indo-Fijian and 22 of other races). Nailaga Nursing Zone 1 has six settlements, mostly occupied by Indo-Fijian, but no registered I-taukei village. It is a sugarcane farming area and mostly inhabited by Indo-Fijians.

The location and accessibility to necessary infrastructure for Nailaga Zone 1 residents are similar

to those of Vunitogoloa. All communities in this zone are accessible to roads, communication network and electricity supply. The status of water supplies in this zone is the same as Vunitogoloa Nursing Station. However, none of the communities is supplied with treated water.

The background of this Nursing Zone is almost similar to Vunitogoloa Nursing Station in terms of how they access essential services. Some of them find it easier to go to Ba Town while some go to Lautoka City where all the divisional government offices for the Western Division are located. However, their designated health facility is the Nailaga Health Center. The health centre has one medical officer, 2 zone nurses, two clinic nurses, 1 IMCI nurse, one recorder, one maid, one pharmacist, one maid and one labourer. The bus service most of the areas, while those living few kilometers inland or further towards the sea may have to walk for some distance before they can catch the public transport.

The source of income for people of Nailaga Zone 1 is similar to those of Vunitogoloa. Sugarcane farming is a predominant activity in the area while few have ventured into subsistence fishing with the selling of fish common along the King Highway in this nursing zone. They also have family members who are now working either in the urban centre, either in Ba or Lautoka. Mothers' education level is the same as Vatukoula and Nailaga and Balevuto. The area has kindergarten and primary schools but no secondary school. Two secondary schools are located nearby in Nailaga Nursing Zone 2 while some children prefer to attend schools in the urban centres of Ba and Lautoka.

Balevuto Health Center

Balevuto Health Center is located in the district of Ba, in Ba Province, also in the western part of Fiji islands. It is approximately 10km up the Toge/Balevuto Road. The Balevuto medical areas are readily accessible through daily bus service. It has a current population of 6036 where a majority (4292) are Indo-Fijian, followed by I-taukei (1733) and only four of other races. This population also include the population of Nalotawa Nursing Station, a nursing station under Balevuto Health Center but located in the most interior hilly region. Children registered under Nalotawa Nursing Station were not included in this study due to its remoteness and other factors such as climate which was likely to affect the result of this cohort study.

Similar to other nursing zones in this study, Balevuto Medical Area is no exception in terms of the provision of necessary infrastructure. However, Balevuto is the only rural area in the Ba and Ra Province that has treated water supply from a single community source supplied to about 60% of its population. This project was only implemented in 2015 after an outbreak of Hepatitis A suspected to originate from this once untreated water source. Approximately 10% of Balevuto Health Center population is not connected to both electricity and mobile communication network. The Radio Telephone (RT) were installed in these affected areas, but they do not work correctly during rainy days. People have to walk up the hills to enable them to connect to a mobile network. The background of Balevuto Medical Area, in terms of accessing essential services, is similar to Vatukoula. Balevuto Health Center has one medical officer, four nurses who are all IMCI trained, 1 one pharmacist, and one labourer. People from Balevuto have to travel down to Ba Town where they access most of the other government services. Apart from the health centre, the Balevuto Police Post is the other government service provided in this area. All areas accessible by roads are serviced by bus except for those communities under Nalotawa Nursing Station. The Nalotawa areas are also having problems connecting to mobile networks

The source of income for people living in Balevuto is primarily farming, either commercial farming in the form of sugarcane or subsistence farming. A commercial poultry farm is also located in the area. Few families have family members who work in companies in Ba Town while some are

market vendors at the Ba Market. In regards to access to education, Balevuto medical areas have eight kindergarten school, eight primary schools and one secondary school. While more than 90% of students in these areas enjoy bus ride to school, less than 10% of them who are located up in Nalotawa are still travelling in 4-wheel drive to reach school. However, when roads are damaged during a massive down, students have to walk to school. According to the Staff Nurse Sereana, the majority of mothers have high school qualification which is similar to the other three nursing zones in this study (Staff Nurse Sereana, personal communication, November 13, 2017). Housing in Balevuto communities has improved over the years. However, overcrowding is still an issue.

Comparison of gold mining and non-mining regions nursing zone

The public health nurses, who are also referred as zone nurses in accordance with the zoning of nursing areas under their respective medical areas, were also critical informants in this study. The mining region was represented by Staff Nurse Tarau as Zone Nurse Vatukoula, while their respective zone nurses also represented the non-mining regions: Staff Nurse Akata as Zone Nurse Vunitogoloa; Staff Nurse Salome as Zone Nurse Nailaga Zone 2; and Staff Nurse Sereana as Zone Nurse Balevuto. They are interviewed to describe: the common illness within their zones, especially for children; their views and experience on current air pollution sources in their zones; possible effect of poor air quality on the respiratory health of children in their zones; their current approaches towards handling respiratory illnesses; and their assessment of current interventions on improvement of child health. The mining region and non-mining region are located within Western Division of Fiji, which is the warmer and drier region of the main island Viti Levu. The climate in the two regions does not vary much as they are situated, on average, approximately less than 40 km away from each other. The responses from the zone nurses were analysed and are presented below.

Common childhood illnesses in the two regions

The mining region listed skin infections, pneumonia and diarrhoea as the most common infections for children. While pneumonia can be related to poor air quality, diarrhoea can be attributed to the untreated water supply supplied to residence of Vatukoula. Skin diseases and diarrhoea can also be attributed to wading in contaminated creeks and on the Nasivi River near which is highly likely to receive the discharge from mining-related activities. High levels of arsenic and other heavy metals have been recorded by past studies. The Zone Nurse has indicated that people have been advised not to swim downward from the mine discharge, however this is always neglected by some. The MO Vatukoula also reported that respiratory infections follow back pain and myalgia as the most common sicknesses for workers. The Zone Nurse also indicated that the most common infection for all ages residing near the gold mine was acute viral infection, with the possibility of a link with overcrowding and poor housing condition. The non-mining region reported the presence of both AURI and ALRI (pneumonia). The Nailaga zone nurse reported pneumonia as the leading cause of childhood illnesses and is most common amongst I-taukei children. Late presentation of cases is the cause to this increase in cases. Skin diseases, mainly scabies and impetigo, follow pneumonia and is also common in I-taukei children. Diarrhea is third on the list. The Balevuto zone nurse reported skin infection, followed by cough, as the main health issues affecting children at Balevuto Health Centre. The nurse stated that the reduction of pneumonia can be attributed to the introduction of pneumococcal vaccines and other vaccines. Programs such as IMCI has helped tremendously on the identification and management of childhood illnesses in Balevuto. In Vunitogoloa, the nurse reported that ARI is first on the

list but it is mainly AURI. Skin infections (scabies and impetigo) is second on the list. The nurse listed some factors that may contribute to the high number of cases, from her experience as a public health nurse, include the dry weather pattern associated with the Western Division with likely to increase dust and dust dispersion during dry, windy days, and indoor air quality. Sugarcane burning is not usual in this area, however, after the Cyclone Winston, farmers have to burn their cane to assist in cutting as the plants fell aground. Compared to communicable diseases, non-communicable diseases (NCD) is most common in the area for adults. There are more Indo-Fijian who suffer from NCD and they are the one who are mostly attending NCD screening, even though their population is less when compared to I-Taukei. However, the lack of attendance to NCD screening by the I-taukei is a concern.

Air pollution sources in the two regions

Gold mining activities are the primary sources of air pollution in the mining region. These include dust from dusty roads, sulfur dioxide from the stack gold treatment plant stack and power generators stack, vehicles fumes, tailing dams and processes within Vatukoula Gold Mine likely to generate air pollutants. The zone nurse indicated that firewood is the most common fuel used for cooking in kitchens. Also, most kitchens in Vatukoula do not have roof chimneys to safely dispose off fumes from the kitchen. However, in the non-mining regions, the sources of air pollution as described by the zone nurses are almost similar, mostly indoor sources and burning of sugarcane. Indoor sources of air pollution in Nailaga include burning of mosquito coils, open fire cooking, use of kerosene stove and indoor smoking. The nurse mentioned that the culture of respect for elders and especially males (parents, in-laws, uncles) in I-taukei family homes discourages mothers and young concerned family members from telling smokers to smoke outdoors. Other factors highlighted by the nurse likely to affect indoor air quality in Nailaga include overcrowding, housing structure and ventilation, which are also known risk factors for ARI. The flowering of sugarcane, burning of sugarcane for harvesting and the increasing backyard burning are familiar outdoor air pollution sources in Nailaga. Air pollutants from these outdoor sources together with the sudden change in weather can be attributed to the increase in wheezing during the cold dry season. The possibility of Rarawai Sugar Mill emissions reaching Nailaga Zone 1, the residence of children used in this study located more than 10km away, cannot be ruled out. This is mainly dependent on wind direction and speed. Sources of indoor and outdoor air pollution in Balevuto and Vunitogoloa are almost similar with Nailaga. Balevuto is also located approximately 10 km away from Rarawai Sugar Mill, while Vunitogoloa is located approximately the same distance away from the Penang Sugar Mill in Rakiraki. The Penang Sugar Mill had closed down in early February 2016 after it was stricken down by Cyclone Winston, the most severe cyclone that has ever landed in Fiji. The dry weather that the west of Fiji is well-known for is likely to increase dust and dust dispersion during dry and windy days, and is an addition to the outdoor air pollution. Those villages and settlements living near the busy and dusty roads are likely to have higher exposure to vehicle fumes.

Air quality and child health in the two regions

The nurses gave differing response as to the likelihood of air pollution increasing the risk of ARI in their zones. The mining region reported that children living next to the gold mine are mostly affected with respiratory illnesses than those living further away, and most cases are recurring. The nurse stated that poor air quality is a threat to the children's health in this mining community. Comparing with Lakeba Medical Subdivision, the medical area that the

nurse previously worked at, Vatukoula has higher incidence of respiratory infection. All nurses from non-mining region reported a decreasing ARI trend from their respective areas. Nailaga zone nurse believed that air quality is a threat to children's health. The nurse stated that poor air quality led to cough and later to pneumonia if untreated. However, the ARI trend in Nailaga medical areas is going down and this can be attributed to the effectiveness of IMCI and the introduction of pneumococcal vaccine. There is always a relationship between a family members coughing resulting in young child under 5 years also catching the cough. In Balevuto areas, the only source of air pollution include dusts during the dry weather, odour from a single poultry farm, and the burning of sugarcane during the harvesting season. However, the ARI trend in this area has decreased which may be due to the introduction of new vaccines, the intensity of awareness on childhood illness identification and management, and the IMCI knowledge by nurses. Vunitogoloa reported no major air pollution except for dust and indoor air pollution, mainly indoor smoking as reported by family members. As the villages in this nursing zone are located near the Kings Highway, it is likely that vehicle fume may affect children's respiratory health. The ARI trend is also decreasing in Vunitogoloa which is the likely outcome of awareness and improved identification and management of cases through the use of IMCI.

Addressing respiratory infections in the two regions

As public health nurses and directly engaging with the children and their families, at times in their home during outreach, they are familiar with the possible risk factors of ARI. The trainings that they have also undergone have prepared them well on the care of children, and the identification and management of childhood illnesses. The nurses lists their activities and experiences related to ARI. In the mining region, the zone nurse stressed that mothers are advised to immediately bring back their children to the health facility when they are sick. The medical team are strongly advising families around Vatukoula on overcrowding as majority of the households are overcrowded with extended families living together. The nurse noticed that respiratory infection has always been neglected or taken lightly by most community members. In Nailaga ARI is addressed through creating awareness during community and clinic visits on factors contributing to ARI, including overcrowding, housing structure and ventilation. Also, during IMCI, emphasis is placed on mothers on the need to bring back the baby immediately if the child continue to remain sick. Overall, in Nailaga, most mothers are aware and concerned about the welfare of their children while a few remain ignorant. Ignorant is an attitude problem which is usually hard to change, but the medical team will continue to create awareness and advice. The Balevuto zone nurse stated their public health team are well trained and are in proactive mood when dealing with childhood illnesses. All the four nurses at Balevuto are IMCI trained. The nurse quoted "the IMCI program has really assisted us on the proper management of childhood illnesses" when describing the benefits of being trained in IMCI. Staffs are on proactive mode all the time and would step out immediately to conduct awareness if cases are coming in from a community. In Vunitogoloa, ARI is addressed through monthly shift clinic and awareness to each village and settlement. Awareness is also conducted during MCH clinic at Vunitogoloa Nursing Stations. According to the Vunitogoloa nurse, if the child suffers from no pneumonia cough/cold, then home remedy is advised, however, if coughing for 5 days in a week, then the child has to be brought in to the nurse for review; if suffering from pneumonia, then the IMCI treatment by nurse is required and to be reviewed after two days; and if the child suffers from severe pneumonia, then referral is made to the medical officer. This is standard IMCI procedure for management of respiratory infections in children. The activities of these public health nurses are almost similar as they all use the same tool and operate under the umbrella business plan of

the Ministry of Health.

Assessment of current activities for addressing ARI in the two regions

When asked if the current programs for childhood health at their medical areas are adequate, all the nurses, both from the mining and non-mining region, stated that there is a need to strengthen the existing programs. In the mining region, the nurse stated that there is a need to improve the communication with the management of VGM. This study found out that currently there is no surveillance system for the Vatukoula mining community. A system has to be established where VGM is notified of all mining-related health issues arising from the residential communities that live close to the mine. This will allow them to take responsibility for their actions and improve their operations to protect both the environment and human health. The Nailaga and Balevuto nurses stated that there is a need to strengthen their awareness in the clinic and do more outreach programs to increase awareness of factors contributing to ARI. The Vunitogoloa nurse stated that nurses had done their best to create awareness. However, they are mindful of some barriers outside their reach likely to hinder the improvement of childhood health. There is a decline in breastfeeding while bottle feeding is increasing. Overall, childhood health is affected by various factors of which some are within the control of MoHMS while external factors determine others. Ways of improving those external factors require the expertise of public health offices to apply life-changing awareness techniques and their ability to work with other sectors who have a direct or indirect role on the improvement of child health.

2 Study design

This explains the study design, settings, participants, variables, data sources, data collection, data storage and management, the descriptive, and statistical analysis methods used to analyse the data. These are described as follows.

This was a retrospective cohort study. The goal of the study was to examine the likely effect of exposure to air pollution due to gold mining activities on upper respiratory tract infection and pneumonia (AURI). One group was exposed to gold mining air pollutants as these children live in areas close to gold mine, referred to as 'living in gold mining region'; while the other group was not exposed to gold mining as they live in separate districts from the other group, and was referred to as 'living in non-gold mining region'. The study involved the retrospective observation of respiratory record of children born in 2011 in the gold mining region and those born in the same year from the non-gold mining region. Their respiratory records were observed from birth until they reached year five with the focus on the first episode of AURI and pneumonia. The data collected from the two regions were used to conduct survival analysis.

Children at birth were free of either AURI or pneumonia. Over time before they reach year five, they may or may not develop respiratory infections due to exposure to air pollutants. The prevalence of AURI and pneumonia were estimated in each group. Survival analysis was conducted to assess the difference between the two groups. The study also used thematic analyses of key informant interview and focus group discussion on examining the possible explanations of the outcome of this cohort study.

3 Setting

All children who were born in 2011 from registered mothers and raised in both the regions (gold mining and non-gold mining) were included in the study. The acute respiratory infection records of each child were retrospectively observed from birth in 2011 until the child reached the fifth birthday in 2016. The children's date of birth and date of fifth birthdays were noted as that was the length of the retrospective observation period. The data containing the AURI and pneumonia records of each child was retrieved from the Integrated Management of Childhood Illness (IMCI) registers kept with the zone nurses at the government public health facilities in the two regions. The IMCI is a WHO tool used by nurses to identify and manage childhood illnesses in health facilities around the country. Nurses have to undergo IMCI training before they can be qualified as an IMCI nurse. The practice in Fiji is that sick children are first seen at the public health facilities (Nursing Stations and Health Centers), where the public health nurse first assesses them before they are referred to the hospital if they are suffering from severe illnesses and meet the criteria for referral. There is nothing stopping parents from taking their children directly to the hospital, as members of the public are always advised to seek medical care in the nearest health facility in times of sickness. The hospitals around the country have designated rooms/space allocated for IMCI works which are attended by an IMCI trained nurse. Therefore, the IMCI registers at the hospitals in the two regions were also attended to and the respiratory record of those seen extracted. The likelihood of some seeking medical care outside of the facilities mentioned above, at some point during the five year observation period, was not ruled out. Therefore, their AURI and pneumonia record during that time was not captured in this study.

4 Population under study

A total of 132 children were born in the gold mining region (Vatukoula Nursing Zone) in 2011 while a combined total of 205 were born in the non-gold mining region (63 from Vunitogoloa Nursing Station; 72 from Nailaga Nursing Zone 1, and 70 from Balevuto Nursing Zones). All these children were included in this study as they reflect an acceptable sample size. The selection of nursing zones in the non-gold mining region was carefully considered to make sure that the two regions are closely comparable except for the operation of the gold mine in the gold mining region. The weather in the gold mining and non-gold mining region were almost the same with minor differences at times as all of the nursing zones in the non-gold mining region are on average located approximately 30 - 40 km away from the gold mining region. The Vatukoula Nursing Zone is located in the Tavua district, the Vunitogoloa Nursing Station in the Ra district, while the Nailaga and Balevuto Nursing Stations are located in Ba district.

One group of children was exposed to gold mining-related pollutants from birth, as children in this group lived within one to two kilometers of the gold mine, and this group was labeled as 'living in the gold mining region'. The 'living in the gold mining region' group lived next to the oldest and single operating mine known as Vatukoula Gold Mine, located in Tavua District, in the western part of Fiji and on the northwest region of Viti Levu, the country's main island. The group was under the care of the Vatukoula Nursing Zone. There are two nursing zones in Vatukoula and children from both zones were combined for this study as they all live near the gold mine. The mine has existed for almost 80 years now. The total number of children in this group was 132.

The second group of children was labeled as those 'living in a non-gold mining region' as they lived in districts not associated with gold mining. The 'living in non-gold mining region' group consisted of children from three separate medical areas outside Tavua District. Two medical areas, Nailaga and Balevuto, are located in Ba District, the district before Tavua along the Kings Highway on the way to Suva, while the third medical area, Rakiraki, is located in Ra District, the district after Tavua, also along the Kings Highway towards Suva. There are two nursing zones in Nailaga Medical Area where Nailaga Nursing Zone 1, located half-way between Ba Town and Lautoka City along the Kings Highway, was selected for this study. In the Balevuto Medical Area, Balevuto Nursing Zone was selected while Vunitogoloa Nursing Zone was selected from the Rakiraki Medical Area. The three nursing zones (Vunitogoloa Nursing Zone, Nailaga Nursing Zone and Balevuto Nursing Zone) are grouped as the non-gold mining region in this study. Vatukoula Gold Mine is located approximately 30 - 40 km away from each of the three nursing zones. Figure 3.3 shows the locations of the three non-gold mining nursing zone and the gold-mining nursing zone. The details of these study groups are explained earlier in this chapter. The number of children in this non-gold mining group was 205.

The Vatukoula Nursing Zone is the gold mining region while the rest of the three (Vunitogoloa, Balevuto and Nailaga Nursing Zones) are grouped as the non-gold mining region in this study

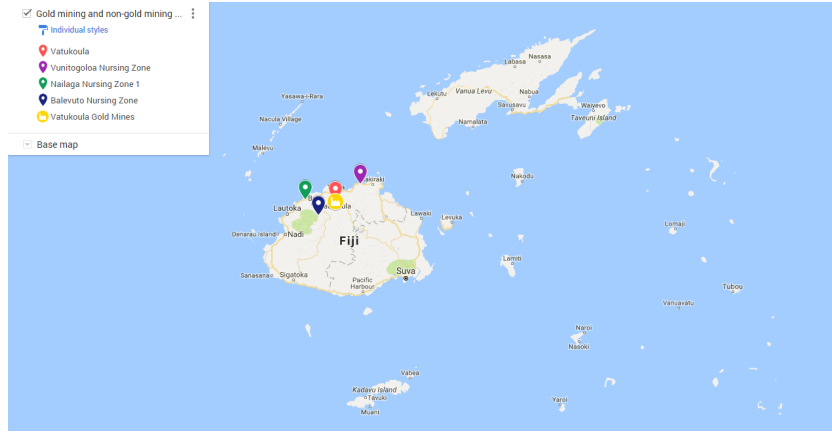


Figure 3.3: Map of study sites (Source: Google map)

5 Variables

5.1 Exposure variable

The exposure variable in this study was residency status. It had two categories, living in gold mining region and living in the non-gold mining region. Living in gold mining region was the group exposed to gold mining-related air pollution while living in non-gold mining region was the group not exposed to any gold mining-related air pollution. While factors such as weather were comparable, the significant difference between the group is the presence of gold mine in the exposed group. The study design and the exposure variable were selected due to the unavailability of reliable data in the mine to independently assess the association between poor air quality and respiratory health-related infections. The VGM had air quality data but were not reliable for

use as the method used for collection of this air quality data does not support its use for causal effect analysis. Therefore, comparing the respiratory health of children living close to the gold mine, who are more likely to get exposed to air pollutants from gold mining activities, with those in an area not associated with gold mining was the most applicable study design.

5.2 Outcome Variable

The outcome variable in this study is an acute upper respiratory infection (AURI) and pneumonia. Using the IMCI guideline is used by nurses to classify respiratory illnesses in the clinics as either 'no pneumonia cough or cold', 'pneumonia', and 'severe pneumonia or very severe disease'. These classifications are recorded in the IMCI register. These classifications are then generally reported as ARI in some of the health facilities while some specify them accordingly as either ARI and pneumonia. (Evelyn, personal communication, December 11, 2017). This study focused on the date of an episode of first AURI or pneumonia as classified by the IMCI nurse in the IMCI register. Those that were classified in the register as 'no pneumonia cough or cold' were grouped as AURI cases in this study, while those that were classified as 'pneumonia' and those with 'severe pneumonia or severe disease' were grouped as 'pneumonia' cases. An acute upper respiratory infection affects the upper respiratory tract, while pneumonia affects the lower respiratory tract.

5.3 Other variables

The variables that were potential confounders in this study were mainly the characteristics of each child that were recorded in the maternal and child health (MCH) registers which include gender, race, birth weight and breastfeeding status. Other potential confounders such as socio-economic data and climate data were also collected but were not used as they did not fit well into the analysis methods used in this study. A survey of the socio-economic status of families of children in this study would have brought in the reliable data that would best fit into the survival analysis method used. This survey was not conducted due to time constraint. The climate data were used to describe the weather during the five years under study, as the two regions are located approximately 40 km apart with the weather in the two regions almost comparable at most times. All confounders except birth weight were categorical. Gender had two categories, male and female; race had three categories, I-taukei, Indo-Fijian and Others; breastfeeding status had two categories, those children who were exclusively breastfed in the first six months of life, and those not exclusively breastfed during that same period. The WHO defines exclusive breastfeeding as the practice of giving an infant breast-milk for the first six months of life [World Health Organization, 2018b]. One of the settings (Vunitogoloa Nursing Station) did not have a record of breastfeeding status while the status of the other three (Vatukoula, Balevuto and Nailaga) were known. Birth weight, a continuous variable, had two categories, those with low birth weight (weight at birth was less than 2500g) and those that did not have low birth weight (weight at birth was greater than or equal to 2500g). The WHO defines low birth weight as weight at birth less than 2500g [WHO, 2018b].

6 Data sources

The AURI and pneumonia data for children in both the gold mining and non-gold mining region were collected from the IMCI registers kept at the nursing stations and hospitals in the two regions. In the gold mining regions, AURI and pneumonia data for children of Vatukoula were collected from the Vatukoula Zone Nurse register at the Tavua Health Center, and from the IMCI nurse's register at the Tavua Hospital. In the non-gold mining region, ARI and pneumonia data for children of Vunitogoloa Zone were collected from the Vunitogoloa Zone Nurse register at the Vunitogoloa Nursing Station, and from the IMCI nurse's register at the Ra District Hospital;; data for children of Nailaga Zone i were collected from the Nailaga Zone Nurse register at Nailaga Health Center; and data for children of Balevuto Zone were collected from the Balevuto Zone Nurse register at the Balevuto Health Center. As both Nailaga and Balevuto are under the Ba Mission Hospital, data were also extracted from the IMCI nurse's register at the Ba Mission Hospital as it held the records of children from these two zones that went straight to the hospital for treatment. An IMCI register with a zone nurse contain the record of respiratory health classifications, and other illnesses encountered by children under five years in that zone.

The data for confounding variables (gender, race, birth weight, breastfeeding status) were collected from the maternal and child health (MCH) registers available with the zone nurses of the four nursing zones. The register contains the vital statistics of children from birth.

6.1 Data Analysis

After cleaning the ARI data, the two groups (AURI and pneumonia) these groups were described using the contingency tables. The analysis and comparison of cases in this study was based only on the two major races (I-taukei and Indo-Fijian) as there was only five children belonging to other races. Variables that had statistically significant p-value were then modeled in the multivariable logistic regression to identify the effect of confounders on the relationship between the exposure and outcome variables. The main statistical analysis carried out in this study was the survival analysis. Survival analysis was conducted on each group separately to identify the proportion of AURI and pneumonia that were likely to remain free from these two infections at the end of the first five years of life. The survival analysis method is described in detail below. The breastfeeding status was grouped into two: those who were exclusively breastfed were labeled as "exclusive breastfed"; while those that were not exclusively breastfed and those with their records unknown were labeled as "no or unknown breastfeeding status".

7 Statistical analysis methods

7.1 Multivariate logistic regression

The effect of residency and race, the two explanatory variables significantly associated with acute upper respiratory tract infection from the bivariate table (Table 4.3), were analysed in the multivariable logistic regression. The same was done for the two explanatory variables that were significantly associated with pneumonia, i.e., residency status and breastfeeding status. This regression method was used to obtain odds ratio in the presence of more than one explanatory variable[Sperandei, 2014]. The result is the impact of each variable on the odds ratio of the

observed event of interest. The confounding effects are avoided when the association of all variables are analysed together[Sperandei, 2014].

7.2 Steps of survival analysis

The survival analysis for AURI and pneumonia were conducted separately. The variables needed for survival analysis include residential status, respiratory infection record, censored, and duration. The residential status was the same as earlier discussed above, i.e., living in gold mining region or living in non-gold mining region. The respiratory infection record was the first episode of either AURI or pneumonia infection a child had in the first five years of life. Only the first episode was recorded and counted as one (1). Those that did suffer an episode of either AURI or pneumonia during the five years were recorded as zero (0). Censored cases in survival data were those that did not experience AURI or pneumonia at the end of the study. a censored child was labeled 1 in the censored column. Those that were lost to follow-up, either due to migration or lost due to competing risks, known as interval censored, and those that did not have an event during the course of observation, known as right-censored, were recorded as censored (1) as they appeared in the dataset[Clark et al., 2003]. This study took both the interval and right censored cases into account in the survival analysis. Those that had their first AURI or pneumonia episode were counted as zero (0) in the censored column. Duration was the time from birth to the time of first episode of ARI. Duration was calculated using RStudio by subtracting the date of birth from the date of first AURI and pneumonia, and reported in weeks.

7.3 Survival analysis

The following analyses were conducted with the survival data described earlier: survival rates and median survival times; Kaplan-Meier curves; log-rank test; hazard ration analysis; and Cox regression. Survival data are normally described and modeled in terms of two related functions. The survivor function and the hazard function[Clark et al., 2003]. The survivor function, usually estimated by the Kaplan-Meier method to describe the survival experience of a study cohort, represents the probability that an individual survives the disease from the time of origin to some time beyond t . [Clark et al., 2003]. The instantaneous potential of having an event at a time, given survival up to that time, is estimated using the hazard function[Clark et al., 2003].

The Kaplan-Meier estimator[Zwiener et al., 2011] was used to calculate the probability of survival for those that did not suffer from acute upper respiratory tract infection in the AURI dataset and those that did not suffer from pneumonia in the pneumonia dataset. The results were then plotted on the Kaplan-Meier curve also known as the survival time curve; with survival times on the x-axis and the probability of survival on the y-axis. The curves plot the proportion of children that have not experienced AURI, for the AURI group, and those that were yet to have pneumonia for the pneumonia group, as a function of time. The little crosses on the survival curves indicate the time (weeks) where participants were lost from the study (censored cases)[Clark et al., 2003]. The "relevant time-point" is when a participant experiences an event (disease) or when someone is lost to the study[Clark et al., 2003]. As in survival curve, a drop in the survival curve or a little cross indicate a relevant time-point.

The difference in survival times between the two groups was statistically compared using the widely used[Clark et al., 2003] standard log-rank test[Zwiener et al., 2011]. This was mainly to compare the two Kaplan-Meier curves to see if there was a statistically significant difference

in the two curves. The survival rates and median survival times for those living in gold mining region and those living in non-gold mining region were obtained after the Kaplan-Meier estimator calculation. The survival rate [Zwiener et al., 2011] was the rate of AURI-free and pneumonia-free at the end of five years while the median survival time was the time at which half of the participants had suffered from AURI or pneumonia in each region. Further to this, there was separate analysis same as the one above, for gender, race, birth weight, and breastfeeding status. The standard log-rank test was used to compare the difference in these groups.

This survival analysis allows inclusion of multiple predictors, both categorical and continuous. In this study, the predictor variables used for analysis include the children's residential status, gender, ethnicity, birth weight and breastfeeding status. The Cox proportional hazard model was used in this analysis. The instantaneous event rate for a particular group of observed people is known as the hazard. The quotient of hazards of two groups is referred to as the hazard ratio and states how much higher is the event rate in one group as compared to the other. The hazard ratio is interpreted as relative risk, and is a descriptive measure used to compare the survival groups times of two different groups under observation[Zwiener et al., 2011]. The confidence interval of the Kaplan-Meier estimator increases as the number of patients at risk decreases[Zwiener et al., 2011]. In this study, the hazard ratio was not reported alone, but also the confidence interval.

The effect of potential confounders, identified from the Cox proportional hazard model above, were then fitted into the multivariate Cox regression to assess their effect on the association between exposure variable (residential status) and the outcome (AURI or pneumonia, depending on the group used).

7.4 Analysis of key informant and focus group discussion responses

This study focused on the effect of gold mining-related air pollutants on the respiratory health of children under five years of age (aged from birth through five years).

The qualitative part of this study was necessary to examine the possible explanation for the second objective, which is to identify the effectiveness of current activities targeting air pollution in Vatukoula. The methods used crucially involved informant interview and focus group discussion. As some of the critical informants also hold key positions in the various government departments, they were also able to give updates on air quality programs at national level.

The second objective of this study require gathering information from key people within the gold mine; senior staffs of the various government department; and community representatives of those living near the mine. Participants of crucial informant interview were selected based on their role in dealing with addressing air quality and air quality related issues in the mine. Participants selected for key informant interview and focus group discussion are listed in Table 3.1. Key informants from VGM include the Environment Officer (referred to as EO-VGM in this report), Medical Officer (referred to as MO-VGM), and Community Relation Officer (referred to as CRO-VGM). Those from government sectors include the Senior Environment Officer, Mineral Resource Department (referred to as SEO-MRD in this report); Senior Environment Officer, Department of Environment (referred to as SEO-DOE); National Advisor Communicable Diseases, MoHMS (Dr Aalisha and referred to as NACD) ; Senior Health Inspector Pollution Control, MoHMS (referred to as SHI Manasa Rayasidamu), Paediatrics Registrar of Colonial War Memorial Hospital and leader of New Vaccines Evaluation Team (Dr Evelyn); Zone Nurse Vatukoula (Staff Nurse Tarau, Zone Nurse Vunitogoloa (Staff Nurse Akata), Zone Nurse Nailaga (Staff Nurse Salome), Zone

Nurse Balevuto (Staff Nurse Sereana) and the Senior Information Officer, MoHMS (referred to as SIO). Since most of the representatives from the government sectors hold senior positions, they were also asked to give insights on the effectiveness of activities targeting air pollution in Fiji. Representatives from the MoHMS were also asked to highlight the effectiveness of programs targeting childhood health in the country. All the zone nurses who kept data on ARI were also asked to give information about the profile of their zone in terms of the likely factors contributing to ARI in their respective zones.

Participants of focus group discussion were representatives from those communities that live near the Vatukoula Gold Mine. These people live and experience the impacts of air pollution related to gold mining, and their contribution was vital as it was used to assess the effectiveness of management approach in addressing air pollution generated by gold mining activities. Selected were village health workers and village headmen. They were asked to discuss their views which were recorded during the focus group discussion.

Data for the qualitative section of this study was collected through key informant interview and focus group discussion. Key informants include key representatives from Vatukoula Gold Mine, senior representatives from the various government departments who have active roles on issues relating to air pollution and human health in Vatukoula, and Fiji. Semi-structured questionnaires were prepared for each key informant and were asked during the interview. Participants were emailed where a brief of the study was described. Attached is the email where the information sheet and consents forms. When the participants agreed they emailed back confirming their willingness to participate. On the interview data, the information sheet was again discussed with them upon which matters of concern were clarified before they were then invited to sign the consent form. The interview then followed this.

Questions to the key informants include the current activities undertaken by their departments to address air pollution and human health; their views on the effectiveness of these activities; the challenges they face; and their thoughts for how well the issue can be addressed. Participants from Vatukoula Gold Mine include the Environment Officer, Medical Officer, and Public Relations, Officer. The environment officer provided information on how air quality is addressed at the mine; the Medical Officer provided some insights into air quality issues and health; and the Public Relations Officer gave some background about the communities around the mine, the issues they face and how the management addresses those issues. A senior representative each from the Department of Environment and Mineral Resource Department provided information on how air quality is addressed in the gold mining industry and Fiji and the effectiveness of their programs. Within the Ministry of Health and Medical Services, National Advisor Communicable Diseases, Senior Health Inspector Pollution Control and Dr. Evelyn of the Paediatrics Department at Colonial War Memorial Hospital and leading a research on childhood pneumonia provided insights into the activities undertaken by the MoHMS to address air quality and health, especially for children under 5 years. All the nurses who were directly involved with the children in this study were also interviewed to access background information about their nursing zones, the activities that they undertake and their effectiveness.

A focus group discussion was conducted for key community member for communities living within the vicinity of Vatukoula Gold Mine to get their first-hand experiences on air quality issues they were facing and the approach by the management to address them. Village health workers and Village Headman were invited as participants of focus group discussion. An invitation letter containing the information sheet and consent form was hand-delivered to each participant. They were given time to read and make the decision. Phone calls were then made to them two days before the discussion to remind them of the activity. The decision to attend was on voluntary

grounds. Those that turned up to the venue were those willing to participate. The information sheet was again discussed with them before they were invited to sign the consent form. A list of questions was prepared for the session. After responses from one question were saturated, the next question was read out and participants shared their experiences. The key informant interview and focus group discussion information sheets, consent forms and questions are attached in Appendix 2 and 3.

Table 3.1: Summary of key informant interviews and focus group discussion

<i>Key informants</i>	<i>Organization</i>	<i>Number invited</i>	<i>Number participated</i>
Senior Managers	MoHMS	4	4
Zone Nurses	MoHMS	4	4
Management staffs	VGM	3	3
Senior Environment Officer	DOE	1	1
Senior Environment Officer	MRD	1	1
<i>Focus group discussion</i>			
Village headman	Vatukoula Community	6	1
Community health workers	Vatukoula Community	5	1

MoHMs: Ministry of Health and Medical Services; VGM: Vatukoula Gold Mine Plc; DOE: Department of Environment; MRD: Mineral Resource Department

The table represents all those that took part in the key informant interview and focus group discussion as the ways of finding the answers to objective two of this study. Representatives from the MoHMS include the National Advisor Communicable Diseases who advises on issues related to NCD; Dr. Evelyn Tuivaga, a Senior Paediatric Registrar in Colonial war Memorial Hospital (CWMH) and the Doctor for New Vaccine Evaluation Project(a collaboration between the Ministry of Health Fiji and Murdoch Children’s Research Institute Melbourne); Senior Health Inspector Pollution, who is in-charge of pollution related activities within the ministry; Senior Information Officer, Mr. Ilesia Ravuci, who gave important information on health data reporting and management within the ministry; and the four zone nurses from the four nursing zones where children data were collected (Vatukoula (exposed group) , and Balevuto, Nailaga and Vunitogoloa (non-exposed groups). These nurses provided a brief profile of their catchment area.

Representatives from VGM include the Environment Officer who is in-charge of all environment-related issues including air quality within then mine; Community Relation Officer who provides a link between the mine and the community within the vicinity of the mine; and the Medical Officer VGM. The Senior Environment Officer of DOE is based in the Western Division of Fiji where the mine is situated and deals with environmental issues within the division. Fiji government’s administrative affairs and services are decentralised within the four divisions (Northern, Western, Central, Eastern). The Senior Environment Officer MRD is also the Acting Director of the department and based at its headquarters in Suva. MRD has its environment unit that deals with all environmental issues related to gold mining and quarry.

All the government and company representatives gave information on the current activities undertaken to address air quality in the mine and Fiji, their effectiveness and the possible way forward for improvement. The MoHMS gave more insight into the activities addressing childhood health. The village headman and community health workers that were part of the focus

group discussion represent the first-hand experience and views of those living within the proximity of the mine, more on how air quality and general health issues have been taken care of by the company. A total of six village headman and five community health workers were invited for the focus group discussion. However, one each turned up from each group. Participant 1 is referred to as FGP1 while Participant 2 is referred to as FGP2 in this report. Feedback from those that attended indicated that the likely reason for non-attendance was due to all schools currently had their annual exams, and it was also the cane crushing season where some would be involved in cane harvesting. The program was scheduled from 0900 to 1030 hours, and it was most likely that parents would be preparing lunch for their children and taking it to school for a meal together with their children at lunch break, a tradition common in most I-taukei dominated schools during important exam days. Even though there were two participants, these two who are in their early 50s contributed a wealth of reliable information as both were raised up in Vatukoula from childhood days.

8 Bias

The possibility of bias in this study cannot be ruled out. There was a possibility of selection bias when selecting the non-exposed to gold mining group. A cohort study would require both the groups to be comparable in most aspects. Therefore, selection of comparable group requires careful assessment. To address this, the living in non-gold mining region group were selected from the two districts close to the gold mining district. The weather in these districts is similar with minor differences. The outdoor environment of these two regions are almost similar as they are located both in the drier part of Viti Levu, less than 40 km away from each other, and also has sugarcane farming as the predominant agricultural activity. However, the indoor environment and the socio-economic factors were likely to differ and were hard to control.

Measurement and recording bias cannot be ruled out during the assessment and recording of ARIs by zone nurses when children were presented with the symptoms at their health facilities. However, these biases are beyond control as this study uses secondary data, one that has already been collected by someone else. Hence, this study did not influence the available data.

9 Study size

The selection of children from the gold mining region and non-mining regions did not use any sampling techniques. Nursing zones in the non-gold mining regions were identified and selected according to their comparable features with the gold mining regions and its size. As all the nursing zones in the non-gold mining region were not overpopulated, involving all the children in the study was advisable to bring up their number, as the single nursing zone in the gold mining region had a higher number of children. The gold mining region (Vatukoula zone) had 132 children while the non-gold mining region had a total of 205 children (63 from Vunitogoloa, 72 from Nailaga, 70 from Balevuto). The number of children in the three non-gold mining nursing zones was similar while the gold mining region had almost double the number of each single non-gold mining nursing zone.

10 Description of quantitative and quantitative data analysis

10.1 Quantitative data analysis

Separate analyses were conducted for the AURI group and the pneumonia group right from the two-way tables, binomial logistic regression, survival analysis, Cox proportional hazard model, and Cox regression. Approximately 1.5% of children were from 'Other' races while the two major races (I-taukei and Indo-Fijian) dominate the cohort. Hence, data analysis and comparison was only conducted on the two major races. It was important to separate the two categories of respiratory infections to enable the identification of the severity of infection in the two cohorts (living in gold mining and living in non-gold mining).

Two-way tables were created to describe each dataset. The first set of two-way tables were conducted to compare the characteristics (gender, race, birth weight and breastfeeding status) of children in the gold mining region and the non-gold mining region. This was then followed by the two-way tables to compare the characteristics of cases, either acute upper respiratory tract infection or pneumonia. P-value and odds ratio with 95% confidence interval was calculated, recorded and described. The alpha of 0.05 was used to test the significance level of the chi-squared test. The chi-squared test of independence does not indicate the strength or direction of any association. The relative risk, odds ratio and attributable risk are all measures of the direction and strength of the association between two categorical variables. The variables that were associated with AURI and pneumonia, having significant p-value and odds ratio were carried forward to the binomial logistic regression.

10.2 Qualitative data analysis

The responses from the key informant interviews on current activities addressing air pollution in Vatukoula Gold Mine and their effectiveness were analysed and grouped into four themes: current activities; effectiveness of these activities; challenges faced when implementing the activities; and the way forward for improvement. The key informants who hold senior positions in government sectors also provide information on national programs targeting air pollution, while those in the MoHMS provided updates on activities targeted towards childhood health. Zone nurses from the four nursing zones gave information about their respective zones which were all compiled to describe their communities.

The second objective of this study was to look at the current activities, policies, programs that address air quality and health at VGM and in Fiji, and to assess their effectiveness. The responses from key informants interviews and focus group discussion were all analysed and grouped into four themes: An answer from each question in each key informant was read and carefully thought before it was placed into the theme that suits it. Some of the answers were weaved into the body of other chapters where they were needed to support some arguments. Questions on current activities to address childhood health were also asked staffs of MoHMS.

The activities undertaken by VGM were assessed followed by those of other departments. Report of Zone Nurse interview was mainly to describe the profile of their nursing zones where children of this study live and also to highlight the most common diseases faced by children in their area of work. The summary of zone nurse interview is available in the study site description of the thesis report.

10.3 Other information

Ethical consideration

Consent and approval were obtained from the following sectors for the purpose before the commencement of this research: University of Canterbury Ethics Committee; Ministry of Health Fiji Research Ethics Committee for health-related research and use of health data; and consent from participants of key informant interview and focus group discussion. The approval copies from the two ethics committee are attached as Appendix 1; information sheets sheets and consent forms are attached as Appendix 2; and key informant interview and focus group discussion questions as Appendix 3.

Chapter 4

Results

1 Comparing AURI and pneumonia in the gold mining and non-gold-mining regions.

There were a total of 337 children in the study, comprising the children from both the gold mining and non-gold mining regions. These were all children born of mothers who were registered with the medical authorities in the two regions. The children were raised in the regions from birth till they were five years old, between 2011 and 2016. Of 337 children, 132 (39.2%) children lived in the mining region (Vatukoula Nursing Zone), and 205 (61%) children belonged to the non-mining region. Of 205 children from the non-mining region, 72 (35% of total) from Nailaga Nursing Zone, 70 (34% of total) from Balevuto Nursing Zone, and 63 (31% of total) from Vunitogoloa Nursing Zone).

Health records collected showed 22 out of 337 (6.5%) children were admitted to the hospitals. Of them, 13 (60%) were related to ARI. There were two (0.6%) deaths from this cohort, both from non-mining region and deaths were not related to either upper respiratory tract infection (UARI) or pneumonia).

A total of 23(6.8%) from the 337 children were lost to follow-up, five from the mining region and 18 from the non-mining region. Twenty-one of those lost to follow-up (91%) migrated out of the four nursing zones while two died. The two dead were classified as a loss to follow-up as their cause of death were not related to either AURI or pneumonia. Therefore, their likelihood of having these two infections if they were still alive is unknown.

The ARI dataset was preprocessed for analysis was used to create the dataset for AURI and pneumonia to facilitated the separate analysis and comparison of infections for the mining and non-mining region. Only two major races, I-taukei and Indo-Fijians, were considered in the analysis, as they dominate the group (65% versus 33%) while only 1% were from Other races, therefore they were excluded from the analysis. All analysis from two-way tables to the multi-variable logistic regression and multivariable Cox proportional hazards regression were conducted separately for the two datasets (AURI and pneumonia). There were 73 AURI cases, where one (1.37%) case was from the mining region and the rest (98.63%) were from the non-mining region; and 135 pneumonia cases, where 79 (60%) were from mining region and 54 (40%) were from the non-mining region.

1.1 Descriptive data

The AURI and pneumonia were analysed separately in all stages of analysis. In every stage of analysis in this report, the AURI group is analysed first, then followed by the pneumonia group. A brief description of all the children in this study cohort was described in Table 4.1

Description of study population

Table 4.1: Description of the study population (n=337)

Variable and categories	Living in gold mining region(No) No.	re- %	Living in non-gold mining region(No) No.	%	p-value
<i>Gender status</i>					
Female	55	36.91	94	63.09	0.52
Male	77	40.96	111	59.04	
<i>Race status</i>					
I_taukei	115	52.04	106	47.96	<0.01
Indo_Fijian	13	11.71	98	88.29	
Other	4	80	1	20	
<i>Birth weight status</i>					
Low birth weight	0	0	22	100	<0.01
Non-low birth weight	132	41.9	183	58.1	
<i>Breastfeeding status</i>					
Exclusive breastfed	99	44.2	125	55.8	<0.05
No or unknown breastfed status	33	29.2	80	70.8	
<i>Respiratory health status</i>					
Neither AURI nor pneumonia	49	38.89	77	61.11	<0.01
Acute upper respiratory tract infection	1	1.37	72	98.63	
Pneumonia	82	59.42	56	40.58	

In the gold mining region (Table 4.1), there were more males than females (40.96% versus 36.96%; $p = 0.52$); more I-taukei than Indo-Fijian (52.01% versus 11.71%; $p = <0.01$); none of the children had low birth weight, however, only 22 children in this study had low birth weight; more exclusive breastfed children than those non-breastfed (44.2% versus 29.2%; $p = <0.05$); and more children suffered pneumonia than AURI (59.42% versus 1.37%; $p = <0.01$) while the rest were free from both.

Describing the acute upper respiratory infection (AURI) group

Male-female ratio was similar in the gold mining region (25.49% versus 24.21; $p = 0.97$) (Table 4.2). More I-taukei (34.96%) than Indo-Fijian (8.11%) live in the gold mining community, $p <0.01$. About 26.63% of non-low birth weight children and no low birth weight child lived in the mining community, $p = 0.07$. About 34% of children exclusively breastfed and 9.59% of those not exclusively breastfed lived in the mining community, $p = < 0.01$. The gold mining region had a single case of acute upper respiratory tract infection.

Table 4.2: Characteristics of AURI group living in gold mining and non-gold mining regions (n=197)

	Living in min- ing region <i>No. (%)</i>	Living in non- mining region <i>No. (%)</i>	p-value
<i>Respiratory status</i>			
AURI	1(1.37)	72(98.63)	<0.001
Neither AURI nor pneumonia	48(38.71)	76(61.29)	
<i>Gender status</i>			
Female	23(24.21)	72(75.79)	0.97
Male	26(25.49)	76(74.51)	
<i>Race status</i>			
I_taukei	43(34.96)	80(65.04)	<0.01
Indo_Fijian	6(8.11)	68(91.89)	
<i>Birth weight status</i>			
Low birth weight	0	13(100)	0.07
Non-low birth weight	49(26.63)	135(73.37)	
<i>Breastfeeding status</i>			
Exclusive breastfed	42(33.87)	82(66.13)	<0.01
No or unknown breastfed status	7(9.59)	66(90.41)	

Table 4.3: Description of acute upper respiratory tract infection cases (n=197)

	Had AURI No.(%)	Without AURI No.(%)	p-value
<i>Residency status</i>			
Living in gold mining region	1(2.04)	48(97.96)	<0.01
Living in non-gold mining region	72(48.65)	76(51.35)	
<i>Gender status</i>			
Female	34(35.79)	61(64.21)	0.83
Male	39(38.24)	63(61.76)	
<i>Race status</i>			
I_taukei	36(29.27)	87(70.73)	< 0.05
Indo_Fijian	37(50)	37(50)	
<i>Birth weight status</i>			
Low birth weight	6(46.15)	7(53.85)	0.69
Non-low birth weight	67(36.41)	117(63.59)	
<i>Breastfeeding status</i>			
Exclusive breastfed	49(39.52)	75(60.48)	0.43
No or unknown breastfed status	24(32.88)	49(67.12)	

Table 4.3 showed that only 2.04% of those living in mining community had AURI while those not living in mining community had 48.65% during the first five years of life, $p < 0.01$. Children not living in the mining community were 48 times more likely to have AURI than those living in the mining community. The proportion of male and female who had AURI were similar (38.24% vs 35.79%, $p = 0.84$). However, males were 1.14 times more likely to have AURI than females. More Indo-Fijian than I-taukei had AURI (50% vs 29.27%, $p < 0.05$). Indo-Fijian children were 2.44 times more likely to have AURI than I-taukei children. 46.15% of those with low birth weight and 36.41% of those with non-low birth weight had AURI, $p = 0.69$. Children with low birth weight were 1.52 times more likely to have AURI than those with non-low birth weight. The proportion of children exclusively breastfed who had AURI were slightly higher than those not exclusively breastfed (39.52% vs 32.88%, $p = 0.43$). Children not exclusively breastfed were slightly more at risk, 1.07 times more likely to have AURI than those exclusively breastfed, but was statistically not significant.

In summary, children who were more likely to have acute respiratory infection were those that did not live in the gold mining region (48.65% vs 2.04%) and those of Indo-Fijian ethnic background (80% vs 57%). These two explanatory variables (residency status and race) were taken further to the logistic regression to identify their adjusted effects on AURI. This suggests that living in non-gold mining region makes the children more at risk of developing an acute upper respiratory infection. As the race was associated with residency status, therefore race is a confounding variable in the association between living in a non-gold mining region or being born and raised in a non-gold mining region in the first five years of life and developing AURI.

Indo-Fijian children were six times more likely than I-taukei children to be living in the non-gold mining region. Also, Indo-Fijian children were 2.44 times more likely than I-taukei children to suffer from acute upper respiratory tract infection (AURI). Finally, children who lived in non-gold mining region were 48 times more likely to suffer from AURI than those who did not live in the gold mining region. The possibility that the effect of living in non-gold mining region on AURI is actually due to one being of an Indo-Fijian race was investigated. A multivariable regression on the likelihood of AURI on the first attack based on race and living in non-gold mining region was conducted.

Multivariable logistic regression of the AURI risk factors

Table 4.4: Multivariable regression results of residency status and race for children with AURI

Variable	Category	Odds (95%CI)	Ratio	p-value
Residency status	Living in mining region	1		
	Living in non-mining	39.6 (5.36, 292)		<0.01
Race	I-taukei	1		
	Indo-Fijian	1.51 (0.80, 2.81)		0.21

Children living in the gold mining area were the reference category in this analysis. Table 4.4 suggests that after controlling for the effects of race, children who lived in the non-mining region were still at higher risk for acute upper respiratory tract infection (OR 39.6, 95% CI: 5.36 – 292), and was statistically significant ($p < 0.01$). The result showed that race is now statistically not significant ($p = 0.21$), living in non-gold mining region is an independent risk

factor for AURI.

Description of the pneumonia group

Table 4.5: Characteristics of pneumonia group living in gold mining and non-gold mining regions (n=259)

	Living in gold mining region	Living in non-gold mining re- gion	p-value
	<i>No. (%)</i>	<i>No. (%)</i>	
<i>Respiratory status</i>			
Neither AURI nor pneumonia	48(38.71)	76(61.29)	<0.05
Pneumonia	79(58.52)	56(41.48)	
<i>Gender status</i>			
Female	53(46.49)	61(53.51)	0.55
Male	74(51.03)	71(48.97)	
<i>Race status</i>			
I_taukei	114(61.62)	71(38.38)	<0.01
Indo_Fijian	13(17.57)	61(82.43)	
<i>Birth weight status</i>			
Low birth weight	0	16(100)	<0.001
Non-low birth weight	127(52.26)	116(47.74)	
<i>Breastfeeding status</i>			
Exclusive breastfed	97(56.07)	76(43.93)	<0.05
No or unknown breastfed status	30(34.88)	56(65.12)	

In Table 4.5, 51.03% male and 46.49% of female lived in the gold mining area, $p = 0.55$. Males were 1.22 times more likely than females to be living in the gold mining community. More I-taukei (61.62%) than Indo-Fijian (17.57%) lived in the gold mining community, $p < 0.001$. I-taukei children were 7.4 times more likely than Indo-Fijian children to be living in the gold mining community. 52.26% of children with non-low birth weight and nil children of low birth weight lived in the gold mining community, $p < 0.01$. 56.07% of exclusively breastfed and 34.88% of non-exclusively breastfed children lived in the gold mining region, $p < 0.05$. Children not exclusively breastfed were 2.35 times more likely to be living in the gold mining community than those who were exclusively breastfed.

More children living in the gold mining area had pneumonia during the first five years of life as compared to those living in non-gold mining areas (62.2% versus 42.42%, $p < 0.01$) (Table 4.6). Children living in the mining community were 2.26 times more likely to have pneumonia than those not living in mining community. About 56.55% male and 46.49% female had pneumonia ($p = 0.14$). Males were 1.56 times more likely to have pneumonia than females. The proportion of pneumonia between the two major races (I-taukei and Indo-Fijian) were similar (52.97% vs 50%, $p = 0.77$). I-taukei children were slightly 1.13 times more likely to have pneumonia than Indo-Fijian children. The proportion of children with low birth weight and those with non-low birth weight who had pneumonia was similar (56.25% versus 51.85%, $p = 0.93$). Children with low birth weight were 1.18 times more likely to have pneumonia than those with non-low

Table 4.6: Description of the pneumonia cases (n=259)

Variables with categories	Without pneumonia No.(%)	Had pneumonia No.(%)	p-value
<i>Residential status</i>			
Living in gold mining region	48(37.8)	79(62.2)	<0.05
Living in non-gold mining region	76(57.58)	56(42.42)	
<i>Gender status</i>			
Female	61(53.51)	53(46.49)	0.14
Male	63(43.45)	82(56.55)	
<i>Race status</i>			
Itaukey	87(47.03)	98(52.97)	0.77
Indo_Fijian	37(50)	37(50)	
<i>Birth weight status</i>			
Low birth weight	7(43.75)	9(56.25)	0.93
Non-low birth weight	117(48.15)	126(51.85)	
<i>Breastfeeding status</i>			
Exclusive breastfed	75(43.35)	98(56.65)	0.053
No or unknown breastfed status	49(56.98)	37(43.02)	

birth weight. More children who were exclusively breastfed had pneumonia than those with no or unknown breast-fed (56.98% versus 43.35%, $p = 0.053$), but not statistically significant. Exclusively breastfed children were 1.8 times more likely to have pneumonia than those not exclusively breast-fed and those of unknown breastfeeding status. In summary, Table 4.6 suggests that children who were more likely to have pneumonia were those born and raised in the gold mining region (62% vs 42%), and was a statistically significant association ($p < 0.05$). Therefore, living in gold mining region is an independent risk factor for pneumonia in this study.

1.2 Outcome data

Survival analysis using the Kaplan-Meier estimator and Kaplan-Meier curve

Without separating acute upper respiratory infection from pneumonia, survival analysis showed children in the gold mining area, the gold mining region in this study, had a higher likelihood of remaining free from acute respiratory infection (ARI) in the first five years of life (Figure 4.1). The ARI, in this case, is a combination of the three classifications of respiratory infection under the IMCI guideline that includes 'no pneumonia cough or cold', 'pneumonia 'severe pneumonia or severe disease'. Therefore, it is a combination of both the acute upper respiratory infection (AURI) and pneumonia. The 'no pneumonia cough and cold' is labeled as AURI, while 'pneumonia' and severe pneumonia and severe disease' are labeled as pneumonia in this study. This crude result was different from what was expected. Further analysis of the dataset was then conducted to find out which of the group, AURI or pneumonia, is prevalent in the gold mining region. The result of this analysis showed a higher proportion of pneumonia was present in gold mining region while the AURI was concentrated in the non-gold mining region. The two groups were then analysed separately using the Kaplan-Meier survival analysis method to identify the proportion of children from each group that did not have either AURI or pneumonia during the first five years of life.

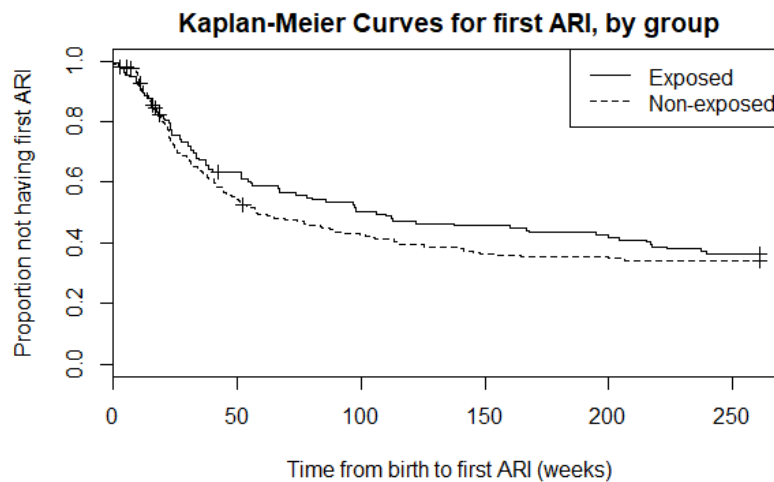


Figure 4.1: ARI-free (both AURI and pneumonia combined) survival curves of the two groups for the first five years of life

Survival analysis using the survival data of the AURI group

AURI-free survival rates by residential status

In the Figure 4.2 children living in mining community had significantly higher likelihood of remaining AURI free in the first five years of life than those not living in the mining region ($p < 0.01$). The median AURI survival time for those not living in the mining region was 126 weeks while those living in the mining community had their survival curve well above the 0.5 likelihood level (refer to Table 4.8 that lists the survival rates at each interval, from birth to five years, in each analysis in the AURI group). The AURI free likelihood for those living in mining region at the end of 26 weeks was 1, as all were free, while those all in the non-mining region was 0.76. The survival rate at the end of 1 year, two years for the two groups, were one vs 0.63, one vs 0.52, while 0.94 vs 0.43 at the end of the study. The hazard ratio for developing acute upper respiratory tract infection in the first five years of life from the residency status of children was calculated using the Cox proportional hazard model.

Table 4.7: Odds of having AURI for children living in non-mining region

Variable	Category	Odds (95%CI)	ratio	p-value
Residency status	Living in mining region	1		
	Living in non-mining region	35.21(4.889 – 253.3)		<0.01

Children in the mining area were given an odds ratio of 1.00 because they were the reference category. Table 4.7 suggests those children living in the non-mining region were at higher risk of developing an acute upper respiratory infection in the first five years of life (OR 35.21, 95% CI: 4.89, 253.3), and was statistically significant ($p < 0.01$)

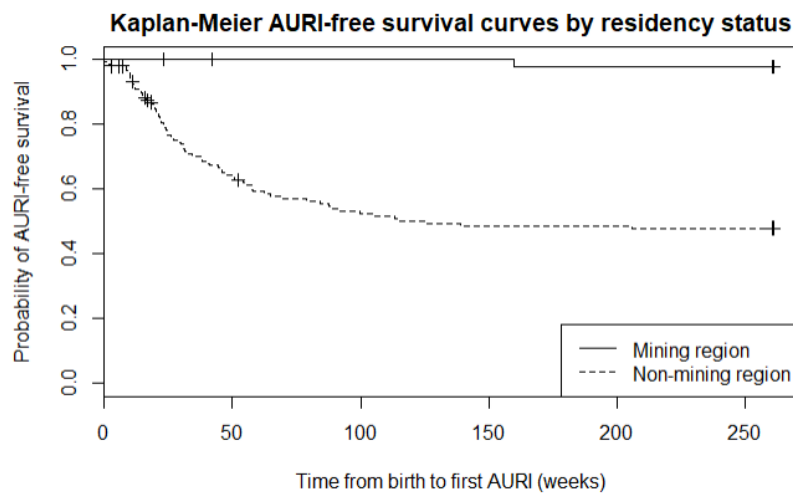


Figure 4.2: AURI-free survival curves for children of the two regions during the first five years of life

AURI-free survival rates by gender

In Figure 4.3, female children had a slightly higher likelihood of remaining AURI free in the first five years of life than male children ($p = 0.63$). Both the survival curves for each gender were above the 0.5 likelihood level, the AURI free likelihood rate of each sex being more than 60%. The survival rate for female at the end of 26 weeks was 0.85 while 0.79 for males. The survival rate at the end of 1 year, two years for females versus males were 0.75 vs 0.69, 0.69 vs 0.6, while 0.62 vs 0.60 at the end of the study period.

The hazard rate for developing AURI in the first five years of life by the gender status of children was calculated using the Cox proportional hazard model.

Table 4.9: Odds of having AURI for male children from the two regions during the first five years of life.

Variable	Category	Odds ratio (95%CI)	p-value
Gender	Female	1	0.63
	Male	1.12 (0.71 – 1.77)	

Female children were the reference category. Table 4.9 suggests that the risk for developing acute upper respiratory tract infection in the first five years of life were 12% more for male children ($OR = 1.12$; 95% CI: 0.71, 1.77), but was statistically not significant ($p = 0.63$).

AURI-free survival rates by race

I-taukei children had a higher likelihood of remaining AURI free in the first five years of life than Indo-Fijian children ($p < 0.05$) (Figure 4.4). The median AURI free time for Indo-Fijian was 106

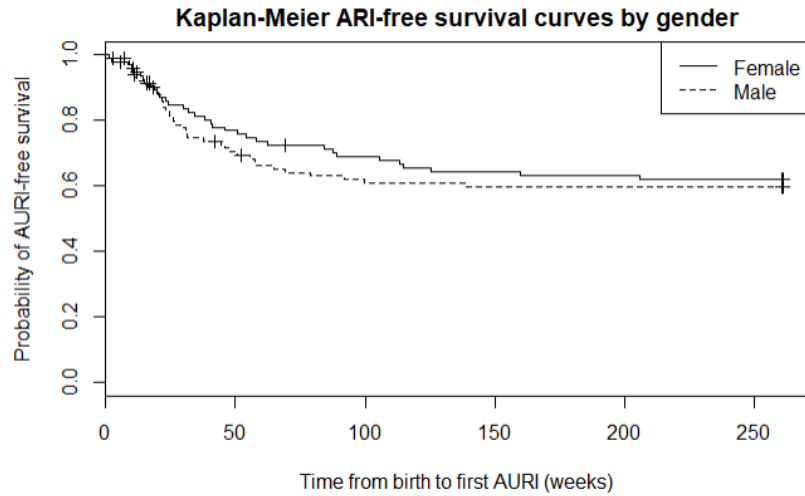


Figure 4.3: AURI-free survival curves by gender of children in both the regions during the first five years of life

weeks while the I-taukei children had their curve well above the 0.5 likelihood mark, indicating that more than 70% of them were free from AURI all throughout the study. The AURI free rate I-taukei at the end of 26 weeks was 0.86 while 0.85 for Indo-Fijian. The AURI free rate at the end of 1 year, two years for I-taukei verses Indo-Fijian were 0.79 vs 0.61, 0.73 vs 0.51, while 0.69 vs 0.47 at the end of the five years. The hazard rate for developing AURI in the first five years of life for the children of both races was calculated using the Cox proportional hazard model.

Table 4.10: Odds of having AURI for Indo-Fijian children from the two regions during the first five years of life.

Variable	Category	Odds ratio (95%CI)	p-value
Race	I-taukei	1	<0.05
	Indo-Fijian	2.03(1.28, 3.2)	

I-taukei children were the reference category in this odds ratio analysis. Table 4.10 suggests that the risk for developing acute upper respiratory tract infection were 2 times higher for Indo-Fijian children (OR = 2.06, 95% CI: 1.28, 3.2), and was statistically significant ($p < 0.05$).

AURI-free survival rates by birth weight

Figure 4.5 shows that in the first five years of life, children with non-low birth weight were more likely to remain AURI-free as compared to those with low birth weight, but this was not statistically significant ($p = 0.75$). The first 1.5 years of life showed those children with a low birth weight having a higher AURI free rate, but the curves interchange at the end of 1.5 years and remained parallel throughout. However, both the curves were above the 0.5 likelihood level, indicating that more than 50% of all children in each group were free from AURI at the end of five years. The AURI free rate for children with non-low birth weight at the end of 26 weeks was

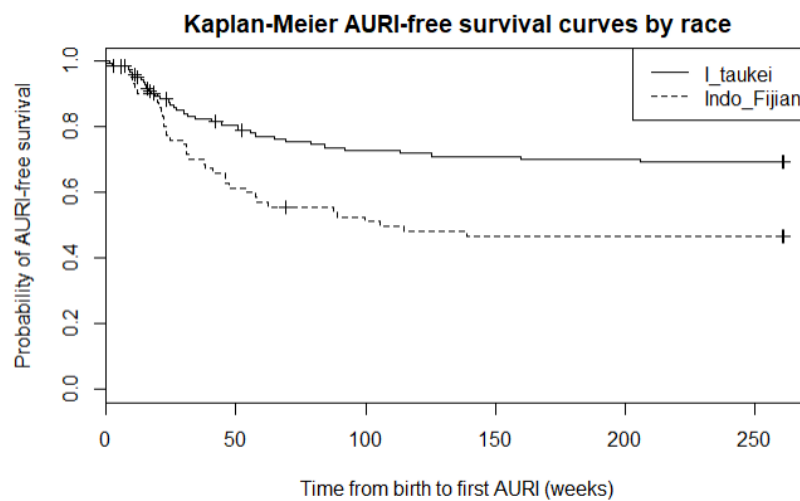


Figure 4.4: AURI-free survival curves of the two races for children from the two regions during the first five years of life.

0.81 while 0.92 for children with low birth weight. The AURI free rate at the end of 1 year, two years for low weight vs non-low weight were 0.72 vs 0.77, 0.66 vs 0.54, while 0.61 vs 0.54 at the end of the five years.

The hazard rate for developing AURI in the first five years of life by the birth weight status of children was calculated using the Cox proportional hazard model.

Table 4.11: Odds of AURI for children with non-low birth weight from the two regions during the first five years of life.

Variable	Category	Odds ratio (95%CI)	p-value
Birth weight	Low birth weight	1	0.75
	Non-low birth weight	0.87 (0.38, 2.01)	

In Table 4.11 Children with low birth weight were the reference category in this analysis. The above table suggests that the risk for developing acute upper respiratory tract infection in the first five years of life is 13% less for non-low birth weight (OR = 0.87; 95% CI: 0.38, 2.01), and was statistically not significant ($p = 0.75$), in other words, children with low birth weights were at higher risk of developing AURI.

AURI-free survival rates by breastfeeding

Children who were not exclusively breastfed with those of unknown breastfeeding status were more likely to remain free from AURI in the first five years of life compared to those who were exclusively breastfed ($p = 0.72$). However, both the curves (Figure 4.6) were above the 0.5 probability level, indicating that more than 50% of all children in each group were free from AURI at the end of five years. The AURI free rate for children of no and unknown breastfeeding status at the end of 26 weeks was 0.83 while 0.81 for those exclusively breastfed. The AURI

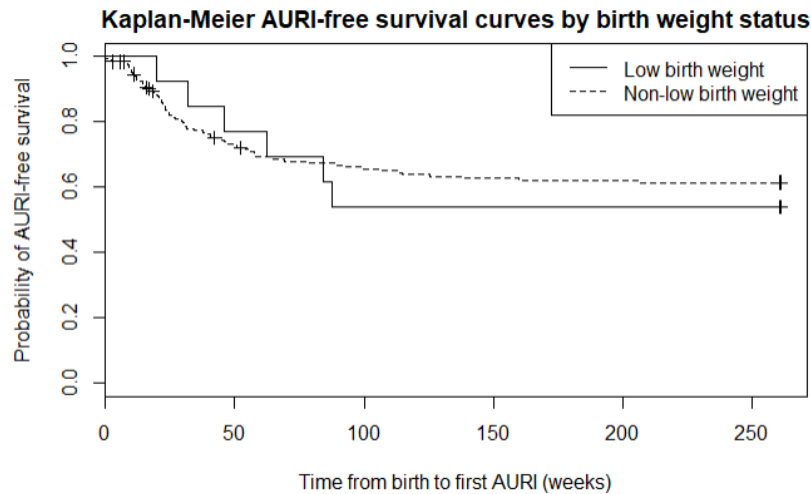


Figure 4.5: AURI-free survival curves for children of low birth weight and those with non-low birth weight during the first five years of life.

free rate at the end of 1 year, 2 years for the no and unknown group vs the exclusive breastfed group were 0.77 vs 0.70, 0.67 vs 0.64, while 0.62 vs 0.60 at the end of the study. The hazard rate for developing AURI in the first five years of life by the breast feeding status of children was calculated using the cox proportional hazard model.

Table 4.12: Odds of AURI for the non-exclusive breastfed children during the first five years of life

Variable	Category	Odds ratio (95%CI)	p-value
Breastfeeding status	Exclusive breastfeeding	1	
	Non-exclusive breastfeeding	0.91 (0.56, 1.49)	0.92

Exclusively breastfed children are given an odds ratio of 1.00 because they are the reference category. Table 4.12 suggests that the risk for developing acute upper respiratory tract infection in the first five years of life is 9% less for non-exclusive breastfed and those of unknown breastfeeding status (OR = 0.91; 95% CI: 0.56, 1.49), and was statistically not significant ($p = 0.72$).

Survival analysis using the survival data of the pneumonia group

Pneumonia-free survival rates by residential status

Figure 4.7 showed children living in the non-mining region having a higher likelihood of remaining pneumonia free than those in the mining region ($p < 0.05$). The survival rates were similar in the first six months and began to widen after the first year. At six months, 80% of those in the non-mining region and 75% of those in mining region were yet to have their first pneumonia. More than half of those in the non-mining region were free from pneumonia as their curve did

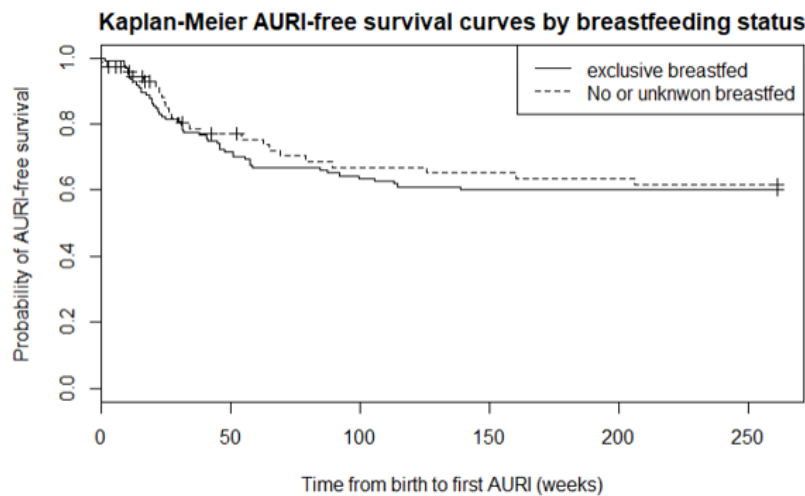


Figure 4.6: AURI-free survival curves of the exclusively breastfed and those children of no or unknown breastfed status from the two regions during the first five years of life.

not come down the 0.5 likelihood level, while those in the mining region went below the 0.5 mark and having a median survival time of 106 weeks (refer to Table 4.14 that lists the survival rates at each interval, from birth to five years, in each analysis in the pneumonia group). The pneumonia free rates for the non-mining and mining region at the end of 1 year, two years were 67% vs 61% and 61 vs 0.50, while 55% vs 37% at the end of five years. The non-mining region curve showed more children being censored (lost to follow up) within the first year of birth.

The hazard rate for children developing pneumonia in the first five years of life by residency status was calculated using the Cox proportional hazard model. Children living in mining region were

Table 4.13: Odds of having pneumonia for children living in the non-mining region during the first five years of life

Variable	Category	Odds ratio (95%CI)	p-value
Residency status	Living in mining region	1	
	Living in non-mining region	0.65 (0.46, 0.92)	<0.05

the reference category in the pneumonia odds ratio calculation for the two regions. Table 4.13 suggests that the risk for developing pneumonia in the first five years of life is 35% less for children lining in non-gold mining region. (OR = 0.65; 95% CI: 0.46, 0.92), and statistically significant ($p < 0.05$). This means that risk of developing pneumonia is statistically significantly high for children living in the gold mining region.

Summary of survival rates from the survival functions of each variable against pneumonia

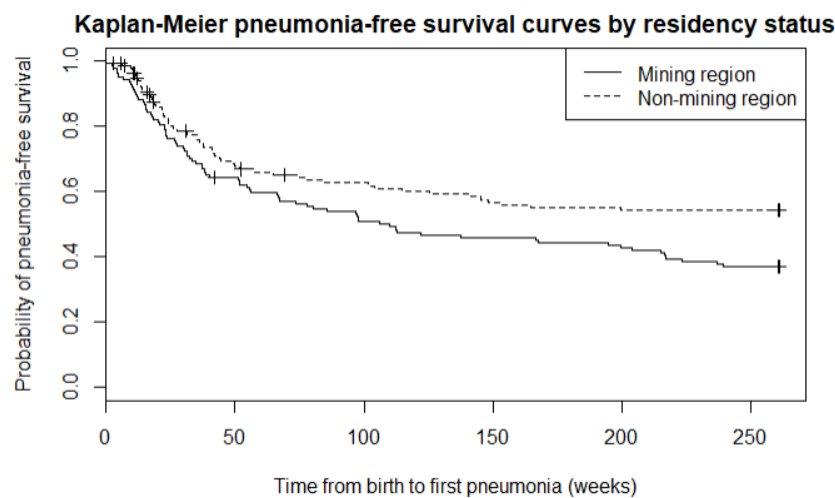


Figure 4.7: Pneumonia-free survival curves for the first five years of life for children living in the mining and non-mining region

Pneumonia-free survival rates by gender

Figure 4.8 shows females having a higher likelihood of remaining pneumonia free than males ($p = 0.11$). The survival rates were very similar in the first six months and began to widen immediately after and kept an almost similar difference throughout. At six months, 78% of female and 77% of males were yet to have their first pneumonia. Only males had their survival rate coming below the 0.5 likelihood mark with a median survival time of 102 weeks. The pneumonia free rates for females versus males at the end of 1 year, two years were 0.71 vs 0.59 and 0.63 vs 0.50, while 52% vs 41% at the end of five years. The male curve also showed more male being censored (lost to follow-up) within the first year of birth.

The hazard rate for children developing pneumonia in the first five years of life by the gender status was calculated using the Cox proportional hazard model.

Table 4.15: Odds of pneumonia for male children in both the regions during the first five years of life

Variable	Category	Odds-ratio (95%CI)	p-value
Gender	Female	1	0.15
	Male	1.33 (0.94, 1.87)	

Female children were the reference category (Table 4.15). The above table suggests that the risk for developing pneumonia during the first five years of life is higher for male children (OR = 1.33; 95% CI: 0.94, 1.87), and was statistically not significant ($p = 0.15$).

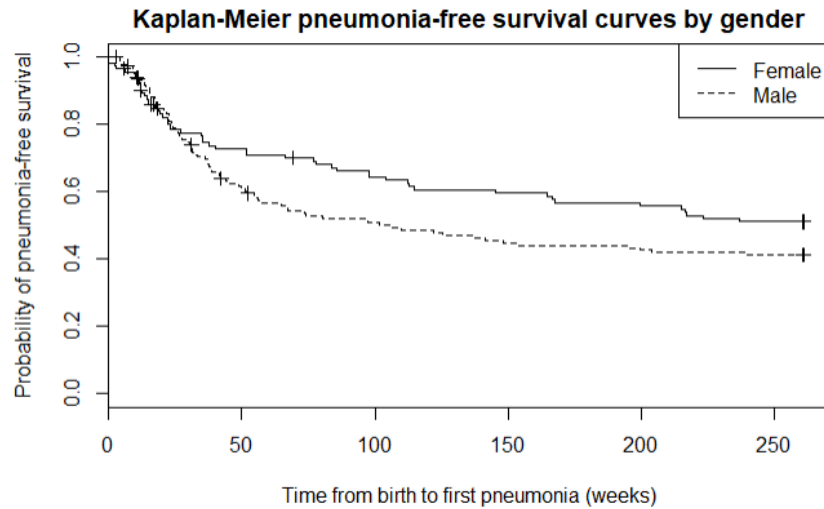


Figure 4.8: Pneumonia-free survival curves for the two gender

Pneumonia-free survival rates by race

The probability of remaining pneumonia free (Figure 4.9) was almost the same for the two ethnic groups as indicated by the two curves ($p = 0.99$). However, the pneumonia-free rate for I-taukei was slightly higher than Indo-Fijian all throughout the first five years, except towards the end of the study when the rate for Indo-Fijian slightly improved above I-taukei. The median survival time for Indo-Fijian was 145 weeks while 195 for I-taukei. The pneumonia free rate for I-taukei verses Indo-Fijian at the end of 6months, 1 year, 2 years were 0.79 vs 0.76 vs, 0.66 vs 0.60, and 0.57 vs 0.54, while 0.45 vs 0.46 after 5 years.

The hazard rate for children developing pneumonia in the first five years of life by race was calculated using the Cox proportional hazard model.

Table 4.16: Odds ratio of pneumonia for the two races

Variable	Category	Odds-ratio (95%CI)	p-value
Race	I-taukei	1	0.985
	Indo-Fijian	0.996 (0.68, 1.46)	

Children of I-taukei race are given an odds ratio of 1.00 because they are the reference category in this odds ratio calculation (Table 4.16). This table suggests that the risk for developing pneumonia during the first five years of life is almost the same for the two ethnic groups (OR: 0.996; 95%CI: 0.68 – 1.46), and was statistically not significant ($p = 0.985$).

Pneumonia-free survival rates by birth weight

The likelihood of remaining pneumonia free was generally higher for those children with non-low birth weight as compared to those with low birth weight ($p = 0.78$). The rates were almost the

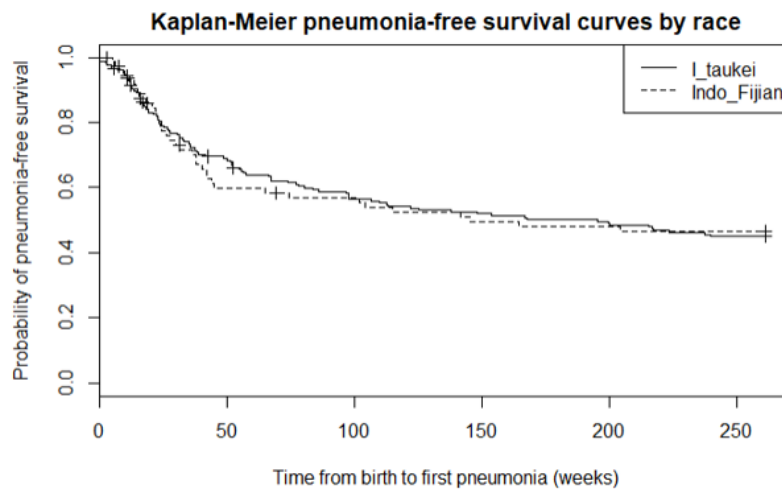


Figure 4.9: Pneumonia-free survival for the two races

same in the first six months before it started to widen until 100 weeks when they met and then widen again following the recent trend with the rates coming closer again at the end of the study period. Both the curves came below the 0.5 likelihood level with the median pneumonia free time for children with non-low birth weight sitting at 168 weeks and 109 weeks for children with low birth weight. The pneumonia free rate for non-low birth weight versus those with low birth weights at six months, one year, two years were 0.79 vs 0.69, 0.65 vs 0.56 and 0.56 vs 0.50, while 0.46 and 0.44 at the end of five years.

The hazard rate for children developing pneumonia in the first five years of life by birth weight was calculated using the Cox proportional hazard model.

Table 4.17: Odds ratio of pneumonia for the low birth weight and non-low birth weight children

Variable	Category	Odds-ratio (95%CI)	p-value
Birth weight	Low birth weight	1	0.78
	Non-low birth weight	1.01 (0.56, 2.16)	

Children with low birth weight were the reference category (Table 4.17). This table suggests that the risk for developing pneumonia during the first five years of life is slightly high for children with low birth weight (OR: 1.01; 95%CI: 0.56 – 2.12), and was statistically not significant ($p = 0.78$).

Pneumonia-free survival rates by breastfeeding status

Children who were not exclusively breastfed with those of unknown breastfeeding status were more likely to remain free from pneumonia in the first five years of life compared to those who were exclusively breastfed ($p = 0.26$) (Figure 4.11). At 142 weeks, half of those exclusively breastfed children had already suffered their first pneumonia while those not exclusively breastfed and

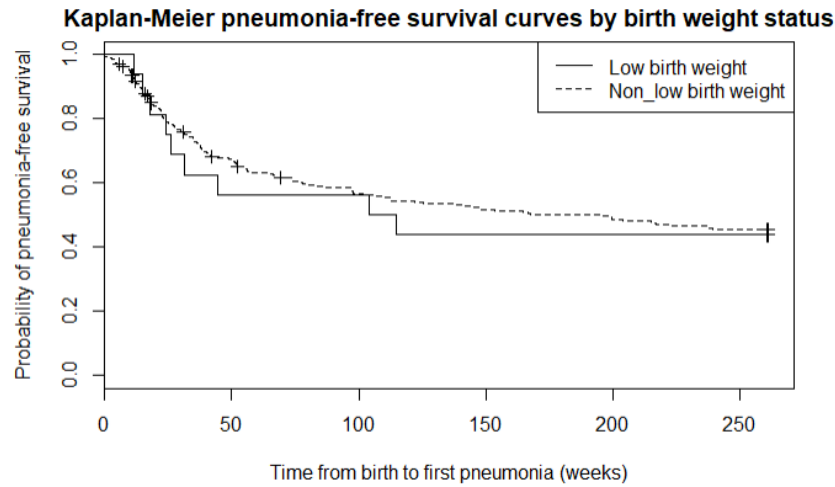


Figure 4.10: Pneumonia-free survival curves for children with low birth weight and those with non-low birth weight

those of unknown status had more than half of their population remained free from pneumonia. The pneumonia-free survival rate of no and unknown breastfed children at the end of 26 weeks was 0.92 while 0.81 for those exclusively breastfed. The AURI free rate at the end of 1 year, 2 years for no and unknown exclusive breastfeeding children vs those exclusive breast fed were 0.68 vs 0.63, 0.66 vs 0.52, while 0.51 vs 0.43 at the end of the study.

The hazard rate for children developing pneumonia in the first five years of life by birth weight was calculated using the cox proportional hazard model.

Table 4.18: Odds ratio of pneumonia for the non-exclusive breastfeeding

Variable	Category	Odds-ratio (95%CI)	p-value
Breastfeeding	Exclusive breastfeeding	1	0.25
	Non-exclusive breastfeeding	0.80 (0.55, 1.17)	

Exclusively breastfed children are given an odds ratio of 1.00 because they are the reference category. Table 4.18 suggests that the risk for developing pneumonia in the first five years of life is 20% less for non-exclusive breastfed and those of unknown breastfeeding status (OR = 0.80; 95% CI: 0.55, 1.17), and was statistically not significant ($p = 0.25$).

1.3 Main results

Cox proportional hazard modeling in the AURI group

Table 4.19 shows the result of cox proportional hazard modeling in the AURI group. Children living in the non-gold mining region had higher risk of getting AURI in the first five years of life than those living in the gold mining region (OR = 35.21; 95%CI: 4.889, 253.3; $p = <0.01$),

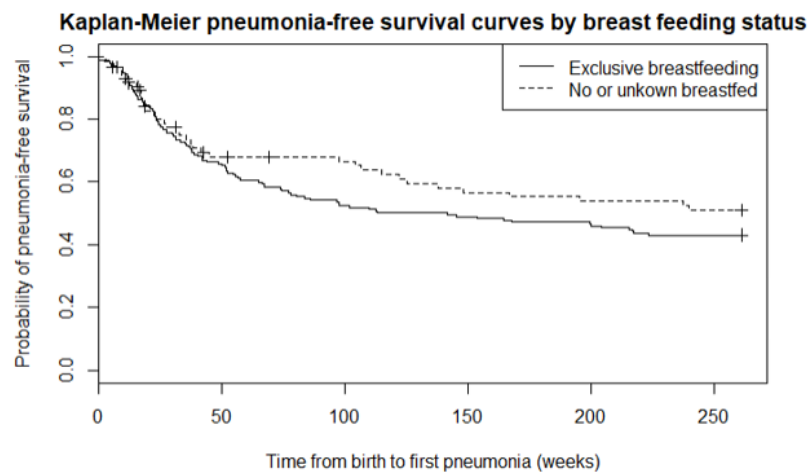


Figure 4.11: Pneumonia-free survival curves for children exclusive breastfeeding and those with no or unknown breastfeeding status.

and was statistically significant. The risk was also high and statistically significant for children of Indo-Fijian race (OR = 2.03; 95%CI: 1.28, 3.2; $p < 0.05$). Male children had higher risk of AURI than females (OR = 1.12; 95%CI: 0.71, 1.77; 0.63), and was not statistically significant. The risk of AURI was lower for children with non-low birth weight (OR = 0.87; 95%CI: 0.38, 2.01; $p = 0.75$), and also for those children with no or unknown breastfeeding status (OR = 0.91; 95%CI: 0.56, 1.49; $p = 0.92$), but were both statistically not significant. Table 4.19 indicates that living in non-gold mining region and Indo-Fijian children were significant risk factors of AURI after the univariate cox proportional hazard analysis.

Multivariable cox regression modeling of AURI risk factors

The effect of race on the relationship between the residential status of children and having acute upper respiratory tract infection was modeled using the cox proportional regression model.

Children in the mining area were the reference category in this analysis (Table 4.20). This table suggests that after controlling for the effects of race, children who lived in the non-gold mining region were more at risk of developing acute upper respiratory tract infection in the first five years of life (OR = 31.92; 95% CI: 4.39, 230.35; $p < 0.001$), and was statistically significant. Therefore, living in non-gold mining region is an independent risk factor for acute upper respiratory infection in this study.

Multivariable cox proportional hazards analysis of pneumonia risk factors

Table 4.21 shows the result of cox proportional hazard models of the pneumonia group. Children living in the non-gold mining region had lower risk of getting pneumonia in the first five years of life than those living in the gold mining region, (OR = 0.65; 95% CI: 0.46, 0.92; $p < 0.05$). The statistically significant p-value indicate that children living in the gold mining region had higher risk of getting pneumonia. Male children and those having non-low birth weight also had

Table 4.19: AURI multivariable model table

Variables	Odds ratio	p-value
Residential status		
Living in gold mining region	1	
Living in non-gold mining region	35.21(4.889, 253.3)	< 0.01
Gender		
Female	1	
Male	1.12 (0.71, 1.77)	0.63
Ethnicity		
I-taukei	1	
Indo-Fijian	2 .03(1.28, 3.2)	<0.05
Bith weight		
Low birth weight	1	
Non-low birth weight	0.87 (0.38, 2.01)	0.75
Breastfeeding status		
Exclusive breastfeeding	1	
Non-exclusive breastfeeding	0.91 (0.56, 1.49)	0.92

Table 4.20: Multivariable cox regression of AURI risk factors

Variables	Odds ratio	p-value
Residency status		
Living in gold mining region	1	
Living in non-gold mining region	31.92 (4.39, 230.35)	<0.01
Race		
I-taukei	1	
Indo-Fijian	1.35 (0.94, 2.0)	0.24

Table 4.21: Pneumonia multivariable model table

Variables	Odds ratio	p-value
Residential status		
Living in gold mining region	1	
Living in non-gold mining region	0.65 (0.46, 0.92)	<0.05
Gender		
Female	1	
Male	1.33 (0.94, 1.87)	0.15
Ethnicity		
I-taukei	1	
Indo-Fijian	0.996 (0.68, 1.46)	0.98
Birthweight		
Low birthweight	1	
Non-low birth weight	1.01 (0.56, 2.16)	0.78
Breastfeeding status		
Exclusive breastfeeding	1	
Non-exclusive breastfeeding	0.80 (0.55, 1.17)	0.25

higher risk of getting pneumonia (OR = 1.33; 95% CI: 0.94, 1.87; $p = 0.15$) versus (OR = 1.01; 95%CI: 0.56 - 2.16, $p = 0.78$), but were both statistically not significant. The risk of pneumonia between the two race was similar (OR = 0.99; 95%CI: 0.68, 1.46; $p = 0.98$). The risk of getting pneumonia was low for children with no or unknown breastfeeding status (OR = 0.80; 95%CI: 0.55, 1.17; $p = 0.25$), but was statistically not significant. Table 4.21 suggests that living in the gold mining region is the single statistically significant risk factor for pneumonia in this study.

2 Effectiveness of air pollution control activities in Vatukoula Gold Mine

2.1 Air pollution control programs by Vatukoula Gold Mine

Environment Management Plans and policies

The Environment Management Plan guided pollution control activities at the Vatukoula Gold Mine, a generic plan for VGM was produced in 2009 (EO-VGM). Currently, the company has 12 environment management plans, and one of them is the Air Quality Management Plan (AQMP). This AQMP illustrates the potential air emissions sources and their impacts; air quality management procedures; roles and responsibilities; training; and monitoring and evaluation of issues related to air quality. The company ensures that Environment Impact Assessment (EIA) was prepared for all new projects. Waste Management Plans were available for specific waste types. The Environmental Policy covers all matters relating to the environment in the mine and compliance with the mining lease issued by the Mineral Resource Department (MRD) is paramount to the company.

The targets of this management plan were to: reduce all air emissions to within appropriate regulatory and industry guidelines; reduce the nuisance factor of dust and stack emissions to

the Vatukoula community; determine current ambient air quality at Vatukoula; demonstrate compliance with Fijian legislation and, where possible, with excellent international practice; and to ensure that no regulatory infringements or community concerns arise due to poor air quality/emissions. Some of the general emission control measures listed in the plan include: use of low sulphur and low aromatic fuel (if available and competitively priced); equipment maintenance in accordance with manufacturer's instructions and at the specified maintenance interval; appropriate training of equipment operators and adherence to equipment operational guidelines and standards; avoidance of vehicle and machinery idling; use of vapour recovery units on fuel/chemical storage tanks; use of dust collection systems for bulk materials unloading; use of covers or dust control devices for crushing and milling operations; minimization of land disturbance; optimization of vehicle movements to eliminate unnecessary vehicle movements; use of cleaner fuels in the powerhouse, in mobile plant and vehicles; fuel switching at the VTP away from sulphur to used oil; use of dust suppression measures throughout VGML operations (wetting work areas, roads, and storage piles, installing equipment covers, minimizing drop distances in conveyor systems and using dust hoods and shields); use of low velocities on all conveyor belts to minimize dust generation; use of cleaning mechanisms for return belts; containment of dust at conveyor transfer points, through use of transfer chutes complete with curtains and rubber seals; prompt rehabilitation or covering of exposed soils and other erodible materials; identification of the individuals with authority to stop work if it does not comply with dust control measures; and enclosure of concentrate stockpiles within the storage buildings.

Meeting regulatory requirements

Regulatory provisions provide guidance and standard on air quality in Fiji. Air quality management in the mine is guided by the Mining Act (Cap 146) and Environment Management Act (Cap 139). These two legislations were captured in VGM's Air Quality Management Plan. The mining lease issued to Vatukoula Gold Mine by the Mineral Resource Department (MRD) sets out the conditions of operation while the air pollution permit issued by the Department of Environment also sets out the conditions that the company must follow to manage and control air pollution. Health and safety of the workers were guided by the Health and Safety at Work Act (1996) while the Public Health Act ensures the operation of this noxious trade does not create a nuisance to those living in its proximity. These legislations guide the operation of the mine to safeguard the environment, workers and the public. These legislations together with the Town Planning Act (Cap 139) were also approving legislation for new projects within the gold mining lease. The EO-VGM indicated that the company is trying its best to comply with all the legislation, policies and plans in place (EO-VGM, personal communication, October 11, 2017).

Air quality measurement

Air quality measurement is a legal requirement under Environment Management Act 2005. The VGM's AQMP requires air quality measurements to be taken from the same locations as vegetation monitoring sites. The Air Quality Management Plan is specifically produced to address air quality issues arising from the gold mining operations. It is a mandatory requirement under Fiji's Environmental Management (Waste Disposal and Recycling) Regulations 2007. According to EO-VGM, air quality monitoring was conducted from 2011 and up until 2015 when it was suspended after a virus attacked all the VGM computer system and lost all the data (EO-VGM, personal communication, October 10, 2017). The company has the air quality data for a total of 24 months only, from 2013 to 2015. Sulphur dioxide (SO₂), nitrogen dioxide (NO₂), nitrogen

2. EFFECTIVENESS OF AIR POLLUTION CONTROL ACTIVITIES IN VATUKOULA GOLD MINE⁸³

oxides (NO_x), carbon dioxide (CO₂), isobutene, and hydrogen sulfide were the air pollutants measured by VGML. A portable Dragger X-am 700 was used by the company to measure air quality during the above period with days for taking measurement pre-planned. The equipment was taken to selected locations where it was turned on for few minutes to take readings (EO-VGM, personal communication, October 10, 2017). A new single unit permanent air quality measuring equipment (AEROQUAL AQM 65), bought by the company to replace the defective portable one, has just arrived from New Zealand during this study. The plan is to place the equipment in selected locations and rotate it over some period to capture air quality around the mine. This is modern equipment which has the capacity to measure up to 10 common air pollutants continuously and ten different environmental parameters [aeroQual, 2018]. The EO-VGM stated that the plan is to purchase few more equipment of the same kind in future and to be permanently stationed on selected locations around the mine to further improve air quality monitoring (EO-VGM, personal communication, October 10, 2017).

Spill Management

Tailing spill is a risk at Vatukoula Gold Mine that needs managing. The EO-VGM confirmed that there were cases of bursting tailing pipes due to wear-and-tear. However, tailings have tailing containing bunds that were able to contain the tailings (EO-VGM, personal communication, October 10, 2017). In case of spillage, all operation in the Vatukoula Treatment Plant (VTP) is stopped. The pipeline is flushed with fresh water, and the pipe is repaired. The tailing is removed from the site and taken to the dam. Crop trial is done to check for the presence of chemicals in products. If the creek is polluted, or other similar accidents occur, the company will carry out mitigation measures within its waste management plan. In 2017, the company only had a single pipe burst. The EO-VGM stressed that the company continuously monitor spillage (EO-VGM, personal communication, October 10, 2017).

Health consideration

The VGM ensures its due diligence towards the mining community in not focusing only on the environment but also on the health of those living within the vicinity of the mine, who were mainly employees of VGM with their families. The EO-VGM indicated during the interview that independent audits were conducted at VGM by a third party where they put forward their findings and recommendations to safeguard the environment and health of the local population (EO-VGM, personal communication, October 10, 2017). The officer further stated that the third party act as a ‘third-eye’ to confirm and verify their compliance with standards.

The VGM has a Medical Officer (MO) that primarily looks after the welfare of staffs from his clinic located near the VGM’s main office. According to the MO, approximately 95% of service is for staffs and only 5% for the general community. The outpatient clinic is open to all staffs (MO-VGM, personal communication, October 10, 2017). Community services include outreach, after-hours emergency response, ambulance service and examination of cases sent from the schools within the vicinity of the mine (MO-VGM). However, as the company primarily looks after its staff, the health needs of the broader community in Vatukoula were taken care of by the government at the Tavua Health Center and Tavua Sub-divisional Hospital. At one time, the government was allocated a space at VGM to conduct MCH and general outpatient department (GOPD) for those that cannot go the hospital for some reasons, however, the space was

taken back by the company thereby discontinuing those essential services ((MO-VGM, personal communication, October 10, 2017)).

According to the Community Relations Officer of VGM, the company is mindful of the safety and well-being of those residing near the mine. “We were very conscious of them as they were our staffs” (CRO-VGM, personal communication, October 24, 2017). Circulars on issues concerning safety and well-being were usually distributed to communities. Valuable information was also disseminated during scheduled public outreach. In most times, this is the forum that community members use to raise their concerns and complains. As for the implementation of proposed projects or works likely to affect the environment and community, the company usually conduct meetings to inform the public and create awareness. However, the MRD will dictate what is to be done at each stage.

To address road dust complains, the gravel and most frequently Haulage Road is usually sprayed with water. On the other hand, sulphur complaints were referred to the environment officer (EO-VGM, personal communication, October 10, 2017). The EO-VGM stated that measures had been taken by the company to address sulphur complains. These include the use of free oil to replace elemental sulphur in the treatment plant and monitoring of air quality. Recently, the company has replaced the 19 diesel generator with nine new generators that will use heavy fuel oil (HFO). However, EO-MRD stated during the interview that the sulphur issue has been there all over the years and also quoted “sa ka tu ga ni veitalanoa” meaning that everyone knows about and can only talk about it. This statement from the MRD, the authority that issued mining lease to VGM, seems to reflect that nothing permanent has been done by those in authority and the company to solve the sulphur issue in Vatukoula, mainly sulphur dioxide from VTP.

The MO indicated that surely there is a relationship between air quality and respiratory diseases in Vatukoula (MO-VGM, personal communication, October 10, 2017). However, there is a need for reliable air quality data and research to highlight the cause and effect relationship effectively. Apart from air quality from the gold mine, the MO stated other factors such as housing status and changing weather patterns which were influencing ARI. The MO noted that there were some extremely hot days and the weather seems to be changing very fast. The comments from the MO indicated the need for reliable air quality data at the mine and effective reporting of health data to Tavua Hospital to enable the proper analysis of cause and effect of air pollution in the Vatukoula.

Even though this report from the company is positive on how they ensure health is protected, its response to community concerns regarding environmental and health risks does not reflect their level of commitment. The EO-VGM and the CRO-VGM have both highlighted the low number of air pollution complaints raised from the residents of Vatukoula. However, on the other hand, participants of focus group discussion had indicated the lack of timely feedback or the no feedback to complaints from the management of VGM.

2.2 Effectiveness of Vatukoula Gold Mine activities

Vatukoula Gold Mines perspective

The management of VGM have taken steps to measure air quality around the mine by using a portable air quality measurement device. Measurement was conducted from 2011 until the first three months of 2015. Even though the mine has been existing for the past eighty years, Fiji’s first environment regulation, Environment Management Act, which requires the monitoring of

air quality was passed in parliament in 2005. Even though air quality measurement was done for that period, the equipment (portable) and method used may be useful for randomly checking air quality and especially during heavy operation hours or when there is a public complain. This method may be similar to screening method listed by the Ministry for the Environment, New Zealand [Ministry for the Environment, 2009]. A site describe screening method as any non-standard method that is used on an exploratory basis and provides indicative data for a particular contaminant. Despite this, the method still needs to have a level of accuracy and precision suitable for the purpose of monitoring [Ministry for the Environment, 2009]. Screening methods were purely indicative methods and any results must be treated with caution. The Ministry for the Environment stressed that screening methods cannot be used to determine compliance with national standards or guidelines [Ministry for the Environment, 2009]. Therefore the method used by VGM may not be beneficial when one tries to compare the air quality data from this method with the standards set under Schedule 5 (National Air Quality Standards), Part A (Ambient Air Quality Standards). The standards set requires standard methods which include continuous measurement and calculation of certain averages, mostly in hours. Therefore, the statement from the EO-VGM that the air pollutants level, which mainly depend on wind direction and velocity, within Vatukoula is always zero, based on the air quality data they measure must be treated with caution. The statement is also contrary to the statements from the SEO-DOE and SEO-MRD who confirmed that the sulphur level is always an issue at Vatukoula apart from other pollutants. To address this gap, VGM has gone ahead and purchased one permanent air quality measurement device from New Zealand in late 2017. To address respiratory infections related to sulphur emissions, the MO report to the management all complains from the residential community. However, the MO highlighted that there is little that can be done to take care of the emissions as the stack have reached their capacity (lifetime) and is not filtering air pollutants, as indicated by the Environment Officer of VGM. This raises questions on the commitment of the management to the AQMP in trying to manage air quality issues within the mine.

Another way to assess the effectiveness programs is by the number of complaints lodged. There is a complain register with the Public Relations Officer which records all complaints from residents of Vatukoula. According to the EO-VGM, the company, on average, gets one formal complaint of air quality in a year. This can be attributed to the effectiveness of the programs undertaken within the Air Quality Management Plan. One way to reduce sulphur dioxide emission was the use of diesel in the treatment plant since 2009 to minimise the use of elemental sulphur (EO-VGM). On the other hand, the low number of complaints can be a reflection of how the management is treating the complaints lodged. Otherwise, the low complaint can be a result of other factors such as the lack of trust from the communities that the company will positively look into their issues. During the focus group discussion, the participants raised the issue of low and no feedback by the company on some of the complaints raised by residents of Vatukoula. Ackley's study provides some insights on the truth of the situation, which were the possible reasons on why the number of complaint to VGM is always low. The study found that even though the residents were highly concerned about the environmental risks and their likely health impacts, they were not comfortable to discuss these risks freely with the company [Ackley, 2008]. The lack of trust in the company by the residents of Vatukoula is likely due to the lack of commitment from the company to effectively communicate the mining-related environmental and health risks of concern to them, and also its lack of action to reduce the risks over the years. A respondent to Ackley's study quoted "*...we have complained many times, but the answers from the management do not satisfy us*" [Ackley, 2008]. From these experiences, it is possible that the community will lodge their complaints to other avenues, either to DOE, MRD, Rural Local Authority or Tavua Hospital, or will choose to remain silent and live with it. The SEO-DOE

and SEO-MRD confirmed during the key informant interview that the main complaint from the mine is sulphur dioxide. Community complaints on air quality related issues should not be taken lightly due to the likely impact it will have on human health.

The statements from the SEO-DOE and SEO-MRD correlates with the experiences of the medical officer who was also a key informant in this study. When asked if air quality was a concern to the residential community, the MO responded, “yes, definitely” (MO-VGM, personal communication, October 10, 2017). The MO highlighted two separate incidences relating to the impact of poor air quality. The first one was an incident at Nasomo just a few months before this interview where a group of mothers and their babies were urgently rushed to the hospital due to their being exposed to sulphur emissions thus developing respiratory symptoms. They were taken for observations and medical care. The MO indicated that this was the first serious incident that he came across involving the community in his three years with the company. Also, sometimes the fumes can change from clear white to black to thick black smoke. The MO had also experienced burning sensation on the back of his throat when he was first exposed to the sulphur. The second incident was when sulphur dioxide emission from the VTP fell near the church. People could not look at each other due to the thickness of smoke. Dust from the sulphur fell at one of the houses near the security office. Dust containing sulphur were visibly present around the house. However, the MO stated that “the nature of gold mining at Vatukoula is that we have some good days and some bad days” meaning that we expect some of these things to happen in some days.

Medical records from the Tavua Hospital of people residing in Vatukoula is another way of assessing the effectiveness of air quality management by the company. Workers were only seen at the clinic owned by VGM while the health needs of all other community members in Vatukoula were addressed by Tavua Hospital. An increase in respiratory problems reported by the hospital for people living in Tavua should trigger an alarm to the management that air quality is not safe. This should transform into action for the company to address air quality and create awareness among the community. However, currently, there is no surveillance system in place between the Tavua Hospital and VGM on diseases related to gold mining. This was highlighted during this study and confirmed by the MO and the zone nurse-in-charge of Vatukoula community (MO-VGM & Tarau, personal communication, October 11 & December 13, 2017).

The company’s relationship with the residents of Vatukoula has generally improved over the years as compared to post-strike in 1991, as witnessed by the community relation officer. However, solving differences between residents and company to address critical issues is not always easy. The ill-feeling against the mine management from those that went on strike is still there (CRO-VGM, personal communication, October 24, 2017). They still count themselves as strikers. However, their children and grandchildren were again employed by the company and not victimised. The ill-feeling was worse before, but things have started to improve now. Strikers were still going to their pocket meeting to sort out pending issues. Despite all this, the management is getting support from the communities on programs that they run (CRO-VGM, personal communication, October 24, 2017).

The Community Relations Officer stated that dust and sulphur were usually the most common public complain at Vatukoula (CRO-VGM, personal communication, October 24, 2017). Residents living near the gravel Haulage Road were mostly affected. Haulage road is a term used for roads designed for heavy and bulky transfer of materials by haul trucks in the mining industry. The complaint is mostly raised from Vatukoula Public School due to its close location to Haulage Road, the most frequently used gravel road by trucks. Before, sulphur used to be the leading cause of complaints, but it is quite normal at present. While complaints about sulphur dioxide remain common, dust is the other common nuisance in the residential community over the years.

2.3 Community experiences on air pollution related to gold mining

The views and experiences of communities within the vicinity of the mine on air quality issues is one way to assess the effectiveness of the VGM and all other government departments in addressing environment and health-related issues in Vatukoula. These were the people who will experience first-hand the likely impacts of gold mining either to their environment or directly on their health. A focus group discussion (FGD) was conducted involving key community representatives. Participants include the village headmen and community (village) health workers. Their views and experiences were compared with the performance of VGM as indicated by the key informants. The outcome of FGD was listed below: The primary sources of air pollution of concern to the communities in Vatukoula that were raised during the focus group discussion include dusty roads and tailing dam, sulphur, vehicle exhaust, and mine ventilation systems. The most prominent two were dust and sulphur. The participants strongly believe that activities related to gold mining were affecting air quality in the area.

Dusty Haulage Road

Dust was the main issue faced by some Vatukoula communities during the raising of Dakovono dam and the retailing of Slime Dam located near Vatukoula Primary School. A total of 170,000 tonnes of tailing were reprocessed in 2016.[World Health Organization, 2017a] Residents of Church Road, Matanagata and Vatukoula Primary School who were located near Haulage Road were exposed to these pollutants on a daily basis during the operation of these two activities. Noise pollution is also an issue arising from these activities. The FGP1 stated that while few roads were tar-sealed, others remain gravel. The participant further stated that even though the roads were gravel, vehicles still travel at higher speed making more dust.

The current retailing of Slime Dam sediments near Vatukoula Primary School is creating many clouds of dust as operations continue for 24 hours daily. The slime dam is situated about 100m away from the school. Sediments from the dam were taken back to the VTP for retailing after approximately ten years of decommissioning. Trucks load of sediments were delivered from the dam to VTP crossing Haulage Road on a daily basis. The focus group participants highlighted that dust from the dam site is reaching the school. The continuous movement of tailing delivery trucks along Haulage Road, which is also close to the school contribute to increasing dust collection to the teachers' quarters, school and residence along this road.

The school which has a roll of 55 early childhood students and 407 primary school students between 5 years and 13 years of age were highly exposed to dust. According to FGP2, dust is experienced at the Vatukoula Public School on a daily basis and is extreme when heavy trucks were delivering materials using Haulage Road (FGP2, focus group discussion, October 27, 2017). Even though the company sprinkle water along this road, the impact is only temporary as the water will dry out only after a while. Residents residing along the Haulage Road were facing this nuisance on a daily basis. Teachers have raised dust complains to the Head Teacher who then raised them to the VGM for action. However, dust is still an issue when this study was conducted. FGP2 stated that a wife of a teacher who resides along Haulage Road was admitted to the hospital alleging dust as the reason for ill-health and admission.

An extensive work to raise the Dakovono tailing dam for re-use commenced between 2014 and 2015 and is still ongoing(EO-VGM, personal communication, October 11, 2017). This requires a considerable volume of soil. Trucks load of soil were transported the open cut mine and delivered to the dam using the same Haulage road as above on a daily basis. The school is about 70m from this road while some homes lie along this Haulage road. According to the FGP1, the road is

continuously used day and night as both the operation, dam raising and retailing were operating 24 hours and on a daily basis (FGP1, focus group discussion, October 24, 2017).

Sulphur emissions from stack

The sulphur from the roaster stack is the main pollution of concern to the community. Inhalation of sulphurous fumes falling in residential communities can cause immediate serious health effects. One of the participants, FGP1, as affected during a sulphurous fumes fallout and quoted the effects as “kama ni tilotilo, warara na ucu, leka na i cegu, kei na so e ra mai pamu saraga i valenibula”, (FGP1, focus group discussion, October 27, 2017), meaning “irritation of nasal passages, burning sensation of nostrils, and some have to be rushed to hospital due to shortness of breath”. FGP 1 was once rushed to the hospital after inhaling sulphurous fumes. There were numerous cases of root crops leaves and vegetables dying out when exposed to sulphur from the VTP. FGP2 quoted “so na gauna, dau lako mai na kubou dromodromo saraga mai na kuvukuvu; na kaukauwa ni sulphur ya ra dau mate saraga kina na draunitavioka, mira na draunibele, ka kecega e ra tu voleka i kea ra mate”, (FGP2, focus group discussion, October 27, 2017) meaning “at times, extremely yellow smoke were emitted from the chimney; the strength of this sulphur had resulted in dying of cassava leaves, falling away of “bele” (*Abelmoschus manihot*) leaves, and basically any vegetation that is close by will die”. FGP1 quoted “e na i tikotiko e Vatukoula, o au mada noqu rai o au baleta na sulphur, ni lutu mai na sulphur me sa kabita dua na draunikau, e vakila saraga na vunika” meaning “in Vatukoula, from what I see, when sulphur drops on a plant’s leaves, the effect is really felt by the plant itself”. FGP1 further stated that roofing iron of houses close to the VTP that came in contact with the sulphur usually get rusted and holes. An example given was that immediately after Cyclone Winston, the management changed some of the roofing irons close to the plant, but now those new roofing irons were having holes as a result of sulphur. If this is the case with plants, image what would the impact be on humans (FGP1). FGP2 noted that recently there is frequent emission of sulphur dioxide, “dua na macawa ya, sa lutu ga e na veisiga”, (FGP2, focus group discussion, October 27, 2017) meaning that “there was a week that we experienced the sulphur emission falling everyday”. According to FGP1, the place where the sulphurous fume falls will be severely affected. The VTP is now operating more frequent than before thereby increasing the frequency of emission. The wider Vatukoula communities were aware and had experiences with the sulphur issue. Concerns and complaints on sulphur nuisance and related health symptoms have been raised to VGM by schools within the vicinity of the mine. The stack from the diesel generators that supply power on 24-hours daily basis to the mine and the Vatukoula community until 2017 is another major source of sulphur dioxide. Sulphur dioxide were also emitted by vehicles and heavy equipment that burn fuel with a high sulphur content.

Past studies have also highlighted the presence of sulphur dioxide as a nuisance and health concern for residents of Vatukoula, and especially to the schools (Emberson-Bain, 1994 & Carmin et al, 2011) Vatukoula Public School is not only exposed to dust but also to sulphur dioxide due to its close location to the treatment plant. Teachers were forced to close the doors and windows of their classrooms as early as 8 a.m. until early afternoon to minimise the children’s exposure to sulphur (Carmin et al, 2011). Apart from this school, there were other schools within the Vatukoula mining lease and in proximity to the mine who were also highly likely to be exposed. This includes Vatukoula Convent School with 303 children (44 early childhood education and 248 primary school students), Nilsen College with 157 secondary school students, and Nasomo village early childhood centre with 23 children and located near a shaft.

Vehicle emissions

2. EFFECTIVENESS OF AIR POLLUTION CONTROL ACTIVITIES IN VATUKOULA GOLD MINE⁸⁹

Together with the dust, the communities fear the emissions from trucks that travel through the Haulage road 24 hours daily carrying materials to and from the gold mine. The Dakovono dam is located few kilometres away from Vatukoula through the Vatukoula-Tavua road and up a gravel road in Toko settlement. Truck emissions and dust impact were likely to be felt by those that reside near this route. Noise from these trucks was also a concern.

Underground ventilation exhaust

A concern also raised by one of the participants was on the mine's four underground ventilation systems that suck the hot and polluted air out from underground and dispose it on the surface and replace it with fresh air. The FGD participants were aware of the locations of four sites: Lololevu, Matanagata/Lomalagi, Smith Shaft just near the VTP, and Bothwick Shaft near Nasomo village. The quality of air from these exhausts is unknown. However, it is raising concern among those residing near them, including the school.

Communities views on the effectiveness of air quality management in mine

The change in management with the change in vehicle models over the years has not reduced air quality issues faced by the residents of Vatukoula over the years. The FGD participants highlighted that the poor air quality status has not changed over the years. This was based on the experiences they have on daily basis.

Dust and vehicle emission management

Dust was second to sulphur dioxide as the two most prominent issues raised when this study was conducted. Those living along the gravel Haulage road continue to face this situation. The spraying of water will work for a while but will leave the road dry and dusty again when the water dries up. The intensity and frequency of use of this road have increased in recent years during the raising of Dakovono dam and retailing of Slime dam (FGP2, focus group discussion, October 27, 2017). These operations commenced during the mid-term of this retrospective study period. Poor air quality complaints still raised from Vatukoula Primary School and residents of Vatukoula. The FGD participants claimed that even though vehicles model has changed from those large ones which generate a lot of fume and noise, this has not made much impact to change the overall air quality around the mine over the years.

Sulphur management

The amount of sulphur pollution as experienced by participants has not changed. The treatment is more intense now as compared to the past. Previously, a treatment used to occur within 2-3 hours daily and at daytime only, but now it is operating almost daily and at both day and night. Also, previously, a siren would sound to warn the members of the community that the treatment plant will soon commence operation (FGP1, focus group discussion, October 27, 2017). However, this is not the case nowadays, and VGM operates the treatment at any time of the day and night without any warning. The unfortunate thing now is that the community was unaware of the operation time of treatment plant. The plant can operate at any time depending on the availability of ore. The siren would warn the community members to take precautionary measures as an operation is about to commence.

As it is an everyday issue, the communities were finding ways to live with it. When a community member could smell the sulphur, they immediately advise children to go inside their homes and close the doors until such time the sulphur gas disappears (FGP2, focus group discussion, October 27, 2017). From the experiences highlighted by the participants and medical officer of sulphur

falling into nearby communities raises the issue of the design of the stack. It seems that the stack does not allow for the dispersion of emission from the exhaust thereby creating a situation where the emission travel together, they get heavier and fall in the residential communities causing severe effects.

Management commitment

Management commitment to addressing air quality is not reflected in the community. This is based on the experiences of the community members which were raised by participants of focus group discussion. The participants stated they had lodged air pollution complaints, but the management said that the situation will always be the same (FGP2, focus group discussion, October 27, 2017). The only advice given was not to cut down trees as they were buffers. By saying that the air pollution situation will always be the same does not reflect the level of commitment that the EO-VGM had earlier stated and also questions the effectiveness of air quality management activities conducted to improve air quality in Vatukoula. One can also question the level of commitment from the company to implement changes that will address air pollution problems; and the commitment to create awareness among communities on the works they were doing and their impacts to reduce fear as existed in an earlier study conducted by Ackley (Ackley, 2008). Even though, the company has outlines activities in its Air Quality Management Plan which when implemented effectively can bring significant improvement in air quality, this outcome should be felt in the communities.

The participants did not see a change in how VGM address their concerns over the years. The company receives and give feedback while in some cases it did not provide any response. The participants also stated that sometimes it usually takes longer for management to come back with feedback. The participants have witnessed the decrease in the company's community visit over the years. The company used to have a monthly visit to communities at one time, but this has decreased (FGP2, focus group discussion, October 27, 2017). During these visits, they provide feedback on some of the people's concerns. In some instances, feedback from the management of the mine is not timely while in some cases there is no feedback. Currently, there is poor communication from the management on important decisions that affect the health and well-being of the local community. Community members were not notified of the operation time of VTP as it used to be the case before. Events of water-cut and power-cut were not relayed to the communities. These were important decisions that affect the daily lives of residents in Vatukoula.

A previous study has recommended awareness of the risk of gold mining-related activities on residents of Vatukoula. Ackley's study recommended for awareness on health impacts of gold mining due to the lack of knowledge by community members on impacts of gold mining. The participants claimed that there was no such awareness conducted. FGP2 stated "e sebera vakadua ni bau caka e dua na veivakararamataki" "meaning that there has never been an awareness done" (FGP2, focus group discussion, October 27, 2017). If that is the case, then this can be a reflection on the lack of commitment from the management to effectively implement the recommendations of independent studies that highlight the risk posed by gold mining activities. A staff of VGM earlier stated that usually third parties were brought in to conduct independent audits of their activities. The outcome of focus group discussion in this study may question the compliance level of VGM to comply with the recommendations of those audits.

Participants of focus group discussion noted that the commitment of the company to the welfare of local communities has significantly reduced over the years. Twenty years ago, there used to be a Health Centre in Vatukoula that caters to the wider community. Now, there is only a doctor and a nurse in a clinic that looks after the workers only. Ninety-five per cent of works conducted

by the clinic were for staff only while the remaining 5% were community-related (MO-VGM, personal communication, October 11, 2017). During the operation of Health Center, staffs used to have membership cards that cater for their whole family, but this has been stopped for most of the staffs when the health centre closed (FGP1, focus group discussion, October 27, 2017). Only a few still enjoy this privilege. The communities feel that they have been deprived of these essential services (FGP2, focus group discussion, October 27, 2017). The Medical Officer earlier stated that space at an old school building in Vatukoula was given to the Ministry of Health to conduct maternal and child health care (MCH) for children and general outpatient department (GOPD) for adults. Space was taken back by the new management thereby discontinuing these essential services. These also reflect the lack of commitment by VGM in providing essential services to residents of Vatukoula who were mostly families of its workers.

2.4 Vatukoula Gold Mine pls response to audit and study findings

Past studies have shown the lack of commitment of companies running Vatukoula gold mine over the years to effectively adhere to the recommendations of various audits and studies conducted. The recommendations were essential to improve the environment and safeguard health. The gold mine has changed ownership over the years since the early 1930s after gold discovery in the area. The Australian Emperor group of companies initially held control of majority of mineral wealth during the influx of foreign investors mainly due to the lack of expertise in technical and financial aspect of gold mining. [Emberson-Bain, 2002, Ackley, 2008] Three companies (Emperor Gold Mining Company Ltd (Emperor), Loloma Gold Mines, and Dolphins Mines Ltd) remained in Vatukoula in 1936 after the end of the gold; then Emperor took full control and acted as sole operator of all the mines in 1959.[Emberson-Bain, 2002, Ackley, 2008] Between 1983 and 1992, the company entered into a joint venture with Western Mining Corporation before regaining full control of the mine again in 1992 and remained so until the 5th of December, 2006. Durban Roodepoort Deep (DRD) of South Africa acquired 100% of this gold mine in 2006 after acquiring 14% of share since 2003.[Ackley, 2008] The mine was shut down and placed for sale in 2006 due to rising operational costs and low output. Emperor Gold Mine's operation and tenement was then purchased by Westech Gold, an Australian company (Government of Fiji, 2013). Shortly after that, in 2008, River Diamonds, a UK-based company, acquired the mine from Westech (Government of Fiji, 2013). River Diamonds was later renamed as Vatukoula Gold Mines Plc, a Chinese company (Wikipedia, 2007). The change of ownership over the years have done little to take serious steps to rectify the pending issues highlighted by various audits and studies. The seriousness of the mines inability to monitor its environmental impacts led the United Nations Environmental and Social Commission for Asia and the Pacific (ESCAP) in 1981 to recommend that the mine's lease should not be renewed until the company (EML) develops a "satisfactory program for monitoring their environmental impacts".[Macdonald, 2004]. The concern of the Ministry of Health and its commitment to assist in the installation of safe water supply in 2003 to replace the untreated river water supply was not permitted by the company.[Macdonald, 2004]. The recommendations of audits conducted by the Oxfam Australian Community Aid Abroad Mining Ombudsman in 2003 on activities related to mining were not undertaken fully by the management of the mine. Two of the most important recommendations was that the company to conduct an independent audit of the occupational health and safety practices at Vatukoula mine and to conduct an independent assessment of the environmental and social impact of mining activities which should be presented in a "transparent and accountable manner" to the public.[Macdonald, 2004]. The management did not respond to the auditor's request for an update on its work on the audit recommendations. This resulted in the auditor conducting a follow-up investigation in 2005

where it was revealed by mine workers that the new management have taken some steps to improve safety. Ackley's study in 2008 found that no environmental education of effects of gold mining on environment and human health was in place and recommended for such education to be conducted. The participants of focus group discussion in this study indicated that there was no such awareness conducted in Vatukoula from 2008 (during Ackley's study) until October 2017 (the date of focus group discussion in this study). Even though the EO-VGM stated that the independent audits by third party act as "third-eye" to confirm and verify VGM's compliance to standards, the level of commitment from the mine management over the years to implement the findings from these audits and studies is questionable.

2.5 Challenges encountered by VGM

The SEO-VGM stressed that the main setback in managing air pollution in the mine is the lifetime of the mine infrastructure itself, which has existed for almost the last 80 years (EO-VGM, personal communication, October 11, 2017). However, this does not limit the effort of the company in implementing the various ways under the AQMP to manage and reduce air pollution. Nevertheless, the EO-VGM indicated that the company is moving forward in trying to modify equipment within the treatment plant that will minimise emissions. A new treatment plant is also proposed (EO-VGM, personal communication, October 11, 2017).

2.6 Future plan by VGM

The EO-VGM stated that they still need improvement and has mapped out ways of doing so. One of the main aim of the company to reduce air pollution as stated by its environment officer is to control emission from the plant. To do this, there is a need to improve every process involved in the extraction of gold from its ore which was mainly conducted in VTP (EO-VGM, personal communication, October 11, 2017). Improving every process will minimise the emission of pollutants. The officer also emphasised the need for the company to ensure that whatever air pollutant that is released from the plant is according to the national standard. The company ensures that every new project has an environmental management plan (EMP) or environment impact assessment (EIA) conducted according to its size. EMP was conducted for all existing operations that were likely to have an impact on the environment (EO-VGM, personal communication, October 11, 2017). A plan is also in place for the protection of trees. A permit is required from VGM if a proposal within the mining lease is likely to disturb the natural vegetation. Lastly, the EO-VGM stressed the need to install permanent air quality measurement devices around the mine. One of the device was purchased and had arrived while this study was underway. The company is proposing to buy few more devices.

Currently, there is no surveillance system in place between the Tavua Hospital and VGM on diseases related to gold mining. This was highlighted during this study and confirmed by the MO and the zone nurse-in-charge of Vatukoula community. The company only acts on complain raised from the hospital but no system in place for continuous surveillance. The Medical Officer support the need for surveillance of diseases related to mining. Regular communication between the VGM and Tavua Hospital is crucial to ensure that the VGM is aware of the diseases likely to be related its operation as all of Vatukoula residential communities, except staffs, receive medical care from the government at Tavua Hospital.

3 Role of various government departments in managing air pollution

3.1 Role of Department of Environment

Current activities by DOE

Even though the MRD issued the mining license with its conditions and has its environment department to monitor compliance, the Department of Environment under the Ministry of Local Government, Housing, Environment, Infrastructure and Transport, is an independent regulatory authority. Backing its existence and operation is the Environment Management Act (EMA) 2005. Waste management, including solid, liquid, air and hazardous wastes were covered in regulations under EMA. The department runs on its own and does consult MRD in cases relating to mining (SEO-DOE, personal communication, November 9, 2017). According to the EO-DOE, the department monitors the Waste Management Plans of VGM. All major developments operating before the introduction of EMA were required to produce their Waste Management Plan (WMP). However, new developments after 2005 which were likely to have impacts on the environment, the proposals need to produce their Environment Impact Assessment report to DOE for endorsement. Therefore, VGM with about 80 years of operation in Vatukoula, did submit its WMPs and receives the waste permits for the various wastes produced as a by-product of gold mining. Recently, a new heavy fuel oil (HFO) power plant, installed to replace the old diesel-run plant, was subjected to EIA which was approved by DOE.

Solving air quality issues within the gold mine require the participation of various stakeholders. The SEO-DEO said that to solve such issues in Vatukoula, the DOE consult MRD and Tavua Rural Local Authority, and they meet with VGML to address those issues. Overall, the maintenance of good air quality in accordance to national standards rely heavily on the active monitoring of MRD and DOE, and the ability of VGM to comply with its own Air Quality Management Plans together with the conditions set out by the two departments. DOE ensures that those with air pollution permits meet the national air quality standards. When the national air quality standards were met, health should not be at risk (SEO-DOE, personal communication, November 9, 2017). Both the departments work under their respective legislation and do consult each other. If a non-compliance falls within DOE jurisdiction (law), the fines will be taken from the EMA 2005, and likewise for MRD where the Mineral Resource Act will apply (EO-DOE, personal communication, November 9, 2017).

Effectiveness of DOE activities and associated challenges

The Environment Management (Waste Disposal and Recycling) Regulations 2007 requires each commercial or industrial facility to hold an air pollution permit if it emits exhaust gases, smoke, steam or dust from any of its premises. The permit holders were required to measure and timely submit air quality data to the DOE every six months. Vatukoula Gold Mine had an air pollution permit and had submitted its air quality data from 2011 to early 2015. The interview of EO-VGM confirmed the submission of air quality data until 2015 when their measuring device became faulty, thereby, suspending all program. The DOE relies on the data supplied by VGM to monitor air quality in Vatukoula, “we rely on the data supplied by VGML, and for the past years, they have been meeting the standards, except for sulphur” (SEO-DOE, personal communication, November 9, 2017). The company is proactive in notifying DOE on some over-the-limit readings

and their mitigation measures. According to the SEO-DOE, the company has its Environment Unit, and they were serious about their business and have implemented measures targeting air pollution. However, there is a definite lack of compliance on submission of air quality data. The SEO-DOE confirmed that for the whole of the Western Division, with five towns and a city, only a single permit holder, Vatukoula, has managed to do this but only for five years. Others who were issued with air pollution permits fail to comply with the conditions of their permits by not submitting their air quality monitoring data.

On the other hand, the officer admitted that the enforcement of this Part 4 of Environment Management (Waste Disposal and Recycling) Regulations 2007, which has provisions for air pollution permits, is weak. The department is aware of its role, but the resources were limited to enable the proper and effective implementation of activities required by the Act. It is also under-resourced, understaffed and lacks the capacity to verify air quality data submitted by industries independently. “We do not have the equipment to monitor air quality” (SEO-DOE, personal communication, November 9, 2017). According to the officer, the ratio of staffs to industries is low. For instance, the Western Division has an allocation of four staff, but currently has two staff only. In reality, these two officers were looking after three large provinces which in total has a city and five municipal councils. The SEO-MRD also agreed that DOE truly lacks resources and human resources to effectively carry out its duties legally provided in the EMA (2005) and its regulations. The Senior Health Inspector in the MoHMS who was also a key informant in this study highlighted from experiences that DOE lacks the ability to monitor the mitigation measures listed in EIA effectively reports basically due to lack of resources and workforce (Manasa, personal communication, October 25, 2017). To effectively submit non-compliance cases to court, the department seeks the assistance of the office of Director Public Prosecution (DPP). The staff also stated the reasons for non-compliance from permit holders would also need to be thoroughly investigated for a better understanding of the problem. “We were doing all the best we can, but we need more improvement in all areas”, said the SEO-DOE (SEO-DOE, personal communication, November 9, 2017). The lack of resources, human resources and capacity, were the main factors limiting the department from exercising its full potential.

Future plan of DOE

The DOE has one of the best environment regulations. However, there were limitations on the part of the department to enforce the regulations addressing air quality fully. Despite all the existing shortfalls, the SEO-DOE believes that there is a bright future ahead. The department, which was under the Ministry of Local Government and Housing, is now a ministry of its own, Ministry of Environment. “I believe we were now recognised because of the work we do and hopefully we will get the resources we need”, said SEO-DOE (SEO-DOE, personal communication, November 9, 2017). Without adequately resourcing this department, one cannot expect air quality management to improve in the mining industry and Fiji.

The SEO-DOE confirmed that the department needs improvement in most areas of air quality control. There is a great need to enforce the existing regulations and standards. The department is also planning to have its air quality monitoring program. These activities were possible when the department is equipped with adequate resources and workforce. Further to these, there is a proposal for each industry and ministry (government) to have its own Environment Management Unit similar to the set up that exist with MRD, or Environment Management Committee similar to the Occupational Health and Safety (OHS) committee established in every workplace (SEO-

3. ROLE OF VARIOUS GOVERNMENT DEPARTMENTS IN MANAGING AIR POLLUTION⁹⁵

DOE, personal communication, November 9, 2017). As for Vatukoula Gold Mine, the officer stressed that there is a need to encourage the company to strengthen their commitment to the community to address air pollution and health.

3.2 Role of Mineral Resource Department

Current activities by MRD

The Mineral Resource Department plays an active role in the management of pollution arising from mining. The department has an Environment Unit, established well before the enactment of Environment Management Act 2005 that specifically looks at related environmental issues in mines. However, the SEO-MRD stated that the unit mainly focuses on solid and liquid discharge and less on emission discharge (SEO-MRD, personal communication, October 25, 2017). Not limiting its role within its unit, the department consults with the Department of Environment (DOE) before a term of reference (TOR) is issued by DOE to a proponent to carry out environmental impact assessment (EIA) for a new mining proposal. The DOE requires and also approves the EIA report with its own set of conditions while the mining lease is processed and issued by MRD also with its own set of conditions. The two departments closely work together with other relevant departments to address environmental issues in mines.

The MRD promote sustainable mining. The mining licensing process is so vigorous that all aspects were covered to ensure that issues were adequately addressed before a license is issued. The work of MRD is purely guided by the Mining Act. The Act has served its purpose over the years. Mining leaseholders were required to comply with the conditions set out by MRD. The department has the authority to cease operation in mine if it fails to comply with the lease conditions and direct the rectification of breach. However, if the leaseholder fails to do so, the performance bond deposited by that particular mining leaseholder to the Director of Mines can be used as an alternative. Unfortunately, the current fine (\$100) under the Mining Act is not a deterrent for future breach.

Mines in Fiji have minimal contribution to the carbon footprint. The SEO-MRD confirmed that even though the mining industry does contribute to air pollution, its contribution to Fiji's carbon footprint is at a negligible level as compared to other sectors such as transport sector and sugar industry. Overall, the mining industry contribution may look insignificant on national figures regarding their air pollution contribution. However, the impact of air pollution generated from mining activities to their immediate surrounding, including environment and human health, is of vital importance.

Effectiveness of MRD activities

Mines in Fiji have been operating smoothly concerning adhering to mining lease conditions. The SEO-MRD stated that on average, MRD is satisfied with the operations of mines in Fiji, but there were always areas for improvement (SEO-MRD, personal communication, October 25, 2017). The MRD promotes sustainable mining. MRD has its environment unit established well before EMA (2005) that looks after environmental issues arising from mining, but as already stated, the unit mainly focuses on solid and liquid discharge and less on air pollution emission (SEO-MRD, personal communication, October 25, 2017). He further stated that as for Vatukoula Gold Mine, one needs to understand that the mine has been operating for last 80 years and therefore has

an old infrastructure with high-risk areas. Despite being old, there were no significant breaches, but minor ones, e.g., late reporting. However, being old is not an excuse for the company to neglect improvements that were required to ensure it operates safely and comply with standards. Therefore, improvement should be made to ensure compliance. The SEO-MRD confirmed that significant improvement is needed in the Vatukoula Gold Mine to address air quality (SEO-MRD, personal communication, October 25, 2017). The company can do more than what they were doing. An alternative design for equipment is one of the ways to reduce emissions. “VGML has the air quality data, but what they were doing with the data is something that needed proper assessment. I do not think they have done some controls to reduce emissions”, said SEO-MRD (SEO-MRD, personal communication, October 25, 2017). Even though the VGM has an air quality management plan, the statements from MRD may question the level of implementation of this plan. It also highlights the need for VGM to put more effort into improving the systems within the treatment plant to reduce pollutant emission levels. From a third-party perspective, the statement also questions the level of commitment by MRD to enforce the conditions of mining lease, and commitment by DOE to enforce the implementation of activities within VGM’s air quality management plan to effect improvement in the treatment plant processes necessary to reduce emission levels.

The MRD is aware and is open to any complaint related to gold mine operation. Experiences from the MRD is that sulphur dioxide is the main cause of complaint from residents of Vatukoula. Sulphur is mainly used in the treatment plant. However, sulphur emitted from the plant gets deposited on trees, roofs, and soil. It gets back to the people through the air they breathe and the water and food (vegetables and root crops) they consume (SEO-MRD, personal communication, October 25, 2017). According to EO-MRD, the gold mine is 80 years old, and therefore this issue has existed over the years (SEO-MRD, personal communication, October 25, 2017). There were two stacks at the mine (mineral stack and generator stack) where sulphur dioxide was emitted. The change of diesel-run generators to heavy fuel oil and the reduction of elemental sulphur recently were two of the essential activities by VGM to reduce sulphur dioxide emissions. The two stacks were the two main source of sulphur dioxide emission in Vatukoula. Participants of focus group discussion mostly refer to mineral stack as the main source of sulphur during the discussion. These activities by VGM were highly likely to reduce sulphur emission from these two sources. However, the lack of reliable air quality data over the years limits the ability to see changes in air pollutant concentrations that should conclude the effectiveness of these approaches.

Future plan for MRD

The SEO-MRD stated that permanent monitoring stations were now proposed for measuring SO₂ levels in Vatukoula. This program is long overdue as sulphur has always been an issue for residents of Vatukoula. The implementation of permanent air quality data measurement to replace the old portable system one is highly appreciated as the data derived will be reliable for comparison against the national standards. The company need to recognise its corporate social responsibility and realise that its existence is not only for economic gain but adequate consideration should be placed on the welfare of those within its vicinity who were mostly residing on its mining lease (SEO-MRD, personal communication, October 25, 2017). Some of the activities may include hiring a doctor, conducting medical outreach and health checks, and other activities likely to address emerging issues from the communities surrounding the mine. Further to this, VGML should self-regulate on best practices and code of practice to improve its footprint (SEO-MRD, personal communication, October 25, 2017).

3.3 Role of the Ministry of Health and Medical Services

Current activities conducted by MoHMS

Activities by Environmental Health (EH) Unit

The Environmental Health Unit is the arm of the MoHMS that deals with all environmental health services required in all communities for prevention and control of the spread of diseases in Fiji. A special senior management post, Senior Health Inspector (SHI) Pollution Control, exists to oversee pollution-related activities likely to impact human health and how well can the human health be protected. The Senior Health Inspector (SHI) in-charge of pollution control programs, Mr. Manasa Rayasidamu, indicated during the interview that the relationship between air quality and health is one of the main targets of the unit (Manasa, personal communication, October 25, 2017). Environmental health related issues including air pollution issues related to health in Vatukoula are handled by the Tavua Rural Local Authority, a statutory body under the Public Health Cap 111, who report to the Central Board of Health of the MoHMS. Apart from health promotion, health awareness, and surveillance, the local authority uses the Public Health Act cap 111 to legally enforce the abatement of environmental health issues likely to pose a threat to human health. In this Act, chemical processing is listed as an offensive trade in the Second Schedule. In case of a nuisance arising from gold mining-related activities, the local authority will have to act immediately and use the regulatory requirement under this Act to safeguard health. The Act defines a nuisance in an offensive trade as “any offensive trade or business so carried on as to be injurious to health or unnecessarily offensive to the public” (Government of Fiji, 1936). The local authority consults the DOE and MRD to avoid the re-occurrence of nuisances. The Zone Nurse Vatukoula indicated that when there is an increase in cases in Vatukoula, nurses usually go out and create awareness to the communities. However, she confirmed that there was never a time when they liaise directly with the gold mine company to address the source of infection (Staff Nurse Tarau, personal communication, December 13, 2017).

Smoke from industries is one of the common public complain raised by the SHI (Manasa, personal communication, October 25, 2017). The SHI stressed that industries would need to improve the servicing of their equipment, just like the servicing of cars, to reduce the level of air pollutant emissions. Timely and effective servicing of equipment in the Vatukoula Treatment Plant and power plant and vehicles used for on-surface deliveries were essential to reduce the release of harmful air pollutants. The Environmental Health Unit business plan contain targets to address the likely impacts of air pollution on health. Indicators from this target were reported on a timely basis from officers on the field throughout Fiji to indicate achievement. One of the yearly indicators is the number of health education conducted (Manasa, personal communication, October 25, 2017). Health education covers both outdoor and indoor air pollutants likely to affect health. More emphasis is placed on indoor air pollutants that may arise from indoor air pollution sources, e.g., smoking and fuelwood burning. Basic awareness includes advising people on proper house and kitchen structure to allow proper ventilation and safe disposal of fuelwood smoke; avoiding indoor smoking; proper housekeeping; safe storage of chemicals within homes; and all other means of minimising indoor air pollution. Reducing indoor air pollution is likely to significantly improve the respiratory health of the at-risk group, children, mothers and elderly, who were more likely to spend more of their time indoors.

Apart from health education, the unit plays a vital role by providing recommendations for air pollution mitigations during environmental impact assessment consultations of new developments,

likely to affect air quality. However, the legal obligation to approve and monitor these mitigation measures lies with DOE. According to experiences, the SHI indicated that there is more emphasis placed by the DOE on the processing of EIA but less on the enforcement of mitigation measures due to lack of resources and human resources (Manasa, personal communication, October 25, 2017). This area needs strengthening for protection of the environment and human health.

The Environmental Health Unit is assisting the MoHMS in replacing the old health care waste incineration plants with the modern dual chamber model (Manasa, personal communication, October 25, 2017). The department is also recommending these new models to other facilities outside the ministry that have incineration plants. The primary chamber is for burning the solid while the secondary chamber is for a 1-2 seconds retention, breakdown and treatment of emissions before their release to the atmosphere. According to the SHI, a dual chamber plant comes with air quality measurement device which record readings of emissions. The department uses the WHO Air Quality Guideline as a reference for emission compliance purposes in Fiji (Manasa, personal communication, October 25, 2017).

The MoHMS receives complaints from the public regarding air pollution generated when incinerating health wastes in medical facilities. The ministry takes these complaints seriously due to the understanding that the ministry is supposed to be the champion of laying platforms for good health, but instead it is doing more harm than good. Measures have been implemented by the installation of dual chamber incinerators in the main hospitals.

Current activities of MoHMS to address ARI in children

The communicable disease section of the ministry led by the National Advisor Communicable Diseases (NACD) lead the programs targeting bacteria and viruses as agents for acute respiratory infection. Programs for addressing air pollution as a risk factor of ARI were pursued by the Environmental Health Unit of MoHMS. The Acting National Advisor Communicable Diseases, Dr Aalisha, stated that from the medical perspective, the MoHMS is currently targeting diseases caused by bacteria and virus (Aalisha, personal communication, November 8, 2017). Vaccination is the main approach by the MoHMS to address ARI for children. Pneumococcal and Hib vaccines were the two vaccines that have helped fight against ARI and contribute to the general improvement of health for children under five since their inception into the Extended Program on Immunization (EPI) (Aalisha, personal communication, November 8, 2017). The mission of immunisation in Fiji as captured by the Fiji National Immunization Policy and Procedure Manual (2013-2016) was to reduce the morbidity and mortality of vaccine-preventable diseases especially those under the EPI, with a long-term aim of improving child health status.[Ministry of Health and Medical Services, 2012] Other programs to address ARI include awareness of cough hygiene during the flu season when cases increase. Awareness is also conducted to address the low health seeking behaviour of parents when children were sick or when children need to attend their regular clinics. Further to vaccination and awareness, MoHMS encourages breastfeeding as one of the main weapons to protect the health of children under five years.

Dr Evelyn Tuivaga, who worked as a Senior Paediatric Registrar in Colonial war Memorial Hospital (CWMH) and as the Doctor for New Vaccine Evaluation Project (a collaboration between the Ministry of Health Fiji and Murdoch Children's Research Institute Melbourne lists the main programs targeting childhood health including IMCI; training of nurses; training of IMCI facilitators by the paediatric team; Paediatric Life Support training targeted for nurses and doctors at Primary Health Care settings to recognize sick children and how to manage them; Advance

3. ROLE OF VARIOUS GOVERNMENT DEPARTMENTS IN MANAGING AIR POLLUTION 99

Paediatric Life Support training targeting doctors and some nurses to improve care of children; WHO Blue Book training of staffs on how to clearly define health conditions; training on neonatal resuscitation; introduction of pneumococcal and rotavirus vaccines; vitamin A and zinc program for diarrhoea in children; and working with NGOs, e.g., recommending the addition of supplements to the food products of manufactured by Floor mills of Fiji (Evelyn, personal communication, December 11, 2017).

As a developing country, Fiji relies on foreign donors support. The Australian Government, through its Department of Foreign Affairs and Trade (DFAT), has supported the Ministry of Health Fiji since the year 2000 on the delivery of essential health services to its people. Its mutual support started with the program known as the *Fiji Health Sector Support Reform Program (FHSRP)* from 2000 to 2003, followed by the *Fiji Health Sector Improvement Program (FHSIP)* from 2003 to 2010, and then to the *Fiji Health Sector Support Program (FHSSP)* from July 2011 to June 2016. All the three programs were managed by Abt-JTA. The FHSSP was valued at \$A33 million with aims to support delivery of effective health services to the people of Fiji and to strengthen health systems.[Adrienne Chattoe-Brown and Majid, 2016]. The five focal areas covered by FHSSP include: "maternal health; child health; non-communicable diseases (NCDs) specifically diabetes and cervical cancer; primary health care revitalisation; and, health system strengthening; plus an Unallocated Fund to allow it to meet emergent and emergency health needs". [Adrienne Chattoe-Brown and Majid, 2016]. DFAT also support other bilateral programs relating to health service delivery outside those mentioned above. Foreign donors such as the Australian Government, in this case, have a huge impact on the success of child health in Fiji.

Effectiveness of MoHMS

Effectiveness of EH unit in addressing air pollution and health

The SHI revealed that the current systems in Fiji were not effective to protect the health of its population from poor air quality (Manasa, personal communication, October 25, 2017). There is a huge gap that exists. Development has intensified over the years. However, a limited emphasis is made on their health impacts. The approach to link impacts of these developments on the environment is clear, but not so on the health of the people. The role of the environmental health officers in EIA is only limited to providing recommendations for health considerations in EIA reports while the DOE has the legal obligation to monitor the mitigation measures. The Environmental Health Unit lacks the regulatory provision for monitoring the implementation of those recommendations that it put forward. Since the primary aim of EIA is to assess the possible impact of a proposal on the environment, the scope of health impact assessment provided in it is insignificant and does not address health impacts in totality. The MoHMS has recognized the need to address this important area. To take care of this, a health impact assessment (HIA) approach is proposed in the new Health Protection Bill (Manasa, personal communication, October 25, 2017). Another issue raised by the SHI was that MoHMS lacks the surveillance mechanism to independently measure air quality as it is in other government departments, including DOE. Health is at risk from air pollution as the air pollutants levels in all parts of Fiji were unknown due to the lack of air quality monitoring mechanisms. The SHI described, from experiences that while more emphasis is placed on the processing and production of the EMP and EIA reports, the monitoring and enforcement of mitigation measures produced in these reports lack due to lack of workforce and resources from DOE (SHI) (Manasa, personal communication, October 25, 2017).

Effectiveness of MoHMS in protecting and promoting child health in Fiji Child health is one of the main focus of MoHMS in Fiji. The country has achieved significant improvement in child health over the years (Aalisha, personal communication, November 8, 2017). Pneumococcal and Haemophilus influenza type B vaccines (Hib vaccine) were two most important factors in this success. Generally, Fiji has achieved big improvement in child health as an outcome of these two vaccines. The efforts of those involved in vaccination over the years should be commended. Vaccination in Fiji began way back in the 1880's with the introduction of the smallpox vaccine (Fiji National Immunization Policy and Procedure Manual, 2013). In 2013, 12 infectious diseases were targeted under the Expanded Program on Immunization (EPI) namely diphtheria, measles, rubella, pertussis, hepatitis B, Haemophilus influenza type b, polio, tetanus, pneumococcal disease, rotavirus, human papillomavirus and tuberculosis (Fiji National Immunization Policy and Procedure Manual, 2013). The burden of certain vaccine-preventable diseases has reduced significantly over the years due to the magnitude and effectiveness of immunisation program (Fiji National Immunization Policy and Procedure Manual, 2013). The MoHMS annual report of 2015 reported general improvement in the immunisation status of one-year-olds and a significant reduction in under-five mortality rate in 2015 and the five years before it. Further to the success by vaccination is Fiji's alignment to MDG and SDG goals and targets. These have improved the surveillance, monitoring, and implementation of activities to facilitate the achievement of indicators set under those goals. Even though the country is doing well regarding these areas, the NACD believes that more improvement is needed to reduce ARI for children under five years (Evelyn, personal communication, December 11, 2017).

According to Dr Evelyn, the IMCI and other programs promoting childhood health were showing positive impacts (Evelyn, personal communication, December 11, 2017). Before there were cases of children collapsing and dying in health centers or nursing station but is not the case nowadays. There has been an increase in early referrals. IMCI has improved the identification of danger signs at the first point of public health services, therefore, assist in early referrals of severe cases. The IMCI came also came with the treatment hence the nurses will know what treatment they can give immediately and what they should refer to a higher level. Deaths in public health facilities have significantly reduced. IMCI has improved the knowledge and skill of nurses on identification and management of ARI for children under five years. The Nailaga Zone 1 nurse stated that ARI trend in Nailaga medical areas is going down and this can be attributed to the effectiveness of IMCI and the introduction of new vaccines such as the pneumococcal vaccine (Salome, personal communication, December 13, 2017). The same sentiment were shared by the Vunitogoloa and Balevuto Zone Nurses, who both added that the intensity of awareness on childhood illness identification and management, and the IMCI knowledge by nurses were the likely factors that contribute to the decreasing trend of ARI in their zones (Akata & Sereana, personal communications, November 10, 2017, & November 13, 2017). The recent evaluation of the effectiveness of pneumococcal vaccine in Fiji by Dr Evelyn's team showed a significant reduction in pneumonia cases in children. This is a positive indication that the introduction of new vaccines, effective implementation of IMCI and other activities by the MoHMS targeted towards children were working and producing the required outcome. The MOH has also increased the capacity of the laboratory to able to address diseases such as ARI.

With the high immunisation rates, the MoHMS still faces challenges that limit the effort to protect child health in Fiji fully. The NACD stated that the low health-seeking behaviour and low socio-economic situations were existing contributing factors to ARI for children in Fiji. Creating awareness of these issues is critical. On the other hand, there is the weak reporting system that still exists locally. The PATIS system is not connected to all health facilities but only divisional hospitals and some sub-divisional hospital as also confirmed by a Senior Information Officer of

MoHMS who was a key informant in this study. Therefore cases reported on PATIS will only reflect those from facilities already connected to this system. However, the National Notifiable Disease Surveillance System (NNDSS) is more representative together with the Annual Reports as their data represent all the health facilities in Fiji. According to the Senior Information Officer, MoHMS, efforts were underway to connect all the facilities to PATIS which should standardise reporting within the ministry.

Future plan of MoHMS

In Vatukoula, the Tavua Rural Local Authority must take necessary approaches to address air pollution complaints coming from residents of Vatukoula. Enforcement of provisions of Public Health Act relevant to these complaints is important. Regularly communicating with VGM on these issues is important to allow the company to make necessary actions to address existing complaints and prevent re-occurrence. Providing advice on the health implications of such complaints, and the impacts of poor air quality on human health is necessary. The local authority should also consult the MRD and DOE promptly informing them of the complaints and how well they can be addressed using the legislation available within these three authorities. The local authority should be vigilant in its role and consider Vatukoula as a high priority area concerning the existence of environmental health risks.

Nationally, the EH unit fully supports the initiatives by the Fiji government to reduce Fiji's carbon footprint. One such initiative is the policy to bring in cars that run on batteries. These were also the approaches that the government is actively engaging in as its contribution to the global fight on climate change. Fiji's contribution to the global climate change effort will have an immediate direct effect on improving air quality and beneficial to human health. Providing government with evidence-based research on health impacts of air pollution is likely to strengthen the government commitment to providing and enforcing policies linked to reducing harmful air pollutant emissions. The impact of these policies will have an immediate effect on the respiratory health of people. The unit is eagerly awaiting the enactment of the Public Health Bill that will provide the legal framework for the MoHMS to deal with human health impacts of developments in totality. This approach will mend the gap that exists in the EIA process.

The MOH is trying its best to manage its carbon footprint by way of ensuring safe incineration methods, segregation of wastes and EH staffs auditing health-care wastes management. Likewise, other ministries were also trying to manage their own. Health is the outcome of multi-sector approach, meaning that healthy people in a country does not lie on the hand of its health sector alone but is very much dependent on the performance of other sectors. As in this study, the health of those in the mining region depends on the performance of Mineral Resource Department and the Department of Environment to effectively enforce the provisions in their respective legislation, and the ability of VGM to fully comply with those regulations. Their performances are likely to dictate the types of health outcomes in this mining region.

Dr Evelyn listed some of the future plan of the MoHMS in relation to child health as: update the classification of IMCI to match world changes; doing surveillance to make sure emerging diseases in children are detected; training of more health workers in management of childhood illnesses; formulating guideline to streamline classification and treatment; making sure availability of antibiotics and drugs (Evelyn, personal communication, December 11, 2017).

Chapter 5

Discussion

1 Summary of main findings from the study

1.1 Risk factors for AURI

The researcher found that based on 337 children followed for five years, thus for 1685 person-years, 138 children were diagnosed with mild, moderate, or severe pneumonia. Hence the cumulative incidence of pneumonia in the entire region (both gold mining and non-gold mining) was about 81.8 / 1000 person-years. The cumulative incidence of UARI for both regions was about 74.7 / 1000 person-years.

The analysis of the AURI group showed that more cases occurred among those children living in non-gold mining region (48 (97.96%) vs 76 (51.35%), $p < 0.001$). The cumulative incidence of UARI in the non-gold mining region was 70.2 per 1000 person-years, and the cumulative incidence of UARI in the gold mining region was 1.51 per 1000 person-years.

Also, in this group, more cases occurred among Indo-Fijian children ($p < 0.01$); male children ($p = 0.84$); children of low birth weight ($p = 0.69$); while the proportion for those children not exclusively breastfed and those exclusively breastfed was similar ($p = 0.99$). However, living in non-gold mining region and Indo-Fijian were significantly associated with acute upper respiratory tract infection ($p < 0.05$). The multivariable logistic regression involving these two variables (residential status and race) showed that living in a non-mining region independent risk factor (OR 39.6, 95% CI: 5.36 – 292) after adjusting for the effect of race. So children who were born and raised in non-mining regions were at higher risk of developing AURI.

This pattern was confirmed in the rate of development of AURI. The Kaplan-Meier estimation of the AURI group showed that the AURI-free survival rates at the end of first five years of life were higher for those living in gold mining region ($p < 0.001$). Also, in this group, the survival rates were higher for female children although not statistically significant ($p = 0.63$); I-taukei children ($p < 0.05$); children of non-low birth weight ($p = 0.75$); and exclusively breastfed children ($p = 0.92$). Univariate analysis found living in non-mining region and race as statistically significant risk factors. Further, multivariable cox proportional hazards regression found that after adjusting for race, living in the non-mining region was an independent risk factor (OR 31.92, 95%CI: 4.39

– 230.35). In summary, the results from this retrospective cohort study suggest that living in the non-mining region was an independent risk factor for AURI.

1.2 Risk factors for pneumonia

The result of analysis of the pneumonia group showed that more cases occurred among children living in gold mining region ($p < 0.05$). The cumulative incidence of pneumonia in the non-gold mining region was 54.63 per 1000 person-years, and the cumulative incidence of pneumonia in the gold mining region was 119.69 per 1000 person-years. Also, in this group, more cases occurred among I-taukei children ($p = 0.77$); male children ($p = 0.14$); children of low birth weight ($p = 0.93$); those children exclusively breastfed ($p = 0.053$). Therefore, living in gold mining region was the single statistically significant risk factor for pneumonia.

The above pattern was similar in the rate of development of pneumonia over the first five years of life in children of the two regions. The Kaplan-Meier estimator calculation of the pneumonia group showed that the pneumonia-free survival rates at the end of first five years of life were higher for children living in non-gold mining region ($p < 0.05$). Also, in this group, the survival rates were higher for female children ($p = 0.11$); Indo-Fijian children ($p < 0.99$); children of non-low birth weight ($p = 0.78$); and those with of no or unknown exclusive breastfeeding status. ($p = 0.26$). Only living in gold mining region had a statistically significant association with pneumonia after the univariate cox proportional hazard analysis. Therefore, living in gold mining region is a statistically significant risk factor increasing the rate of pneumonia in this study.

2 Strengths of this research

Firstly, as this was a retrospective cohort design which allowed the longitudinal observation of participants records for a period of five years, it ensured that all infants were first exposed or non-exposed to gold mining related pollutants prior to development of pneumonia. Secondly, this study took all the children who were born in the four nursing zones (one in gold mining region and three in non-gold mining regions) and follow them up, therefore, there was no scope of sampling error.

3 Limitations of this research

As with other studies, this study had some limitations, which were likely in the areas of site selection, sample selection, missing data, data availability and literature availability. Finding a comparable and exchangeable cohort group is one of the main limitations in cohort studies. A cohort study would require the two groups to be interchangeable, meaning that there is comparability with respect to other determinants of outcome. However, this is not always possible.

Even though the gold mining region and the non-gold mining region in this study were comparable in climate and general outdoor environments, except for gold mining air pollution as in the mining region, the socio-economic factors were likely to be different among the two groups. There is a possibility that the socio-economic status of a household will determine its indoor air quality.

Low-income earners in Fiji are more likely to use firewood and kerosene stove for cooking compared to those of higher income earner who are most likely to use cleaner fuels. Globally, approximately 3 billion people still use solid fuels (wood, coal, crop wastes, dung, or charcoal) in open fires and leaky stoves to cook and heat their homes [World Health Organization, 2017c]. When used, such inefficient fuels and technologies generate high levels of household air pollution. Such household air pollution caused 4.3 million deaths globally in 2012 [World Health Organization, 2017c]. The risk of disease from exposure to household air pollution is unusually high for women and children, accounting for 60% of all deaths attributed to such pollution [Organization et al., 2016]. Poor housing status has also been reported in Vatukoula by past studies. These factors were not observed in this study due to time constraint. Hence these potential confounding variables were adjusted for in the multivariable models.

This study focuses on children under five years old. This age group spend the early part of their lives indoor, therefore likely to have higher exposure to indoor air pollution during this period. However, the relationship between indoor and outdoor levels in Vatukoula is unknown. Various factors are likely to determine this relationship. The selection of this group is a likely source of bias in this study.

Proper recording, storage and reporting of health data is a challenge in developing countries health systems, including Fiji. The health facilities where data were collected for this study were all using a manual system for recording and storing (book system) except for one who was using both book and electronic for storage and reporting. The possibility of misrecording and misreporting cannot be ruled out when dealing with health data in manual forms. The Tavua Hospital where Vatukoula children are seen had missing IMCI registers which totaled 108 days. The Ba Mission Hospital, the main hospital in the non-mining region had missing IMCI registers which totaled 589 days. Registers at Ba Mission Hospital were attended to, to minimise bias in recording data, as some parents usually take their children to the hospital instead of the health center in their areas. Vunitogoloa Nursing stations had the breastfeeding status of children unknown, which was likely due to change of staff over the years. However, Balevuto Health Center and Nailaga Health Center provide all primary health care services to children in the non-mining region. A total of 12 ARI cases belonging to Nailaga Health Center catchment area were extracted from the Ba Mission Hospital IMCI registers during the period 2011 to 2016. National data on childhood respiratory illnesses available with the MoHMS electronic reporting system, PATIS, is unreliable to be used for research purposes as it only contains data of only those health facilities that are connected to this system (SIO, personal communication, December 11, 2017).

There is a possibility that ARI record of some children in this cohort may be recorded in other health facilities when they traveled outside of the mining and non-mining regions as defined in this study. These data were not captured as the three health facilities in this study cannot access the PATIS, the electronic data information system of the MoHMS. Therefore, these data are lost and not reflected in this study.

Studies on impacts of gold mining pollutants on air quality and health, especially for medium and large-scale gold mining are scarce. More works of literature are available on the impacts of gold mining on water bodies, soil, sediments and plants as compared to impacts on air quality. Consequently, more time was taken to search for the required and relevant works of literature to use in this study.

4 Interpretation of result

4.1 Residential status with AURI and pneumonia

Living in a non-mining region and acute upper respiratory tract infection

The high prevalence of acute upper respiratory tract infection in the non-gold mining region can be attributed to three factors: the indiscriminate burning of household refuse; the high amount of sugarcane farms that are burnt during the harvesting season; and the presence of sugar mills more than 10km away from each site. Both the gold mining and non-gold mining communities were comparable in most factors except for these three factors which were present in the non-exposed group. The indiscriminate open burning of any kind is not permitted in the Vatukoula Gold Mining (VGM) lease which also accommodate more than 80% of the population of Vatukoula Nursing Zone, the exposed area. Confirmation from the Medical Officer (MO) through phone conversation on 04/05/2018 is that, apart from the use of open fire in kitchens for cooking, a permit has to be obtained from the Fire Department of VGM before one can burn an open fire on the mining lease. The MO also states that there were few individuals, as is always expected in any community, who would try and violate this policy. However, this is not the case for those residing in non-gold mining communities. People residing in this areas burn anything they want to burn. Regulations limiting burning of household garbage exist in Fiji but are hardly enforced. This indiscriminate burning of household garbage is likely to be one of the contributing factors to the high prevalence of acute upper respiratory infection in the non-gold mining areas. The indiscriminate burning of household and garden waste at the backyard is a common practice throughout Fiji (both rural and urban). The practice is even prevalent in the capital city (Suva Municipality) which has ongoing garbage services as highlighted by a study conducted by Isley et al., (2016).[Isley et al., 2016] A survey conducted in 2014 by this team found that most Suva residents, more than half, burn a proportion of their household and garden wastes. The burning of household wastes followed vehicle emission as the second highest contributor of PM_{2.5} and black carbon (BC). It contributed to 50 +/- 14 t of PM_{2.5} per year and BC between 2.1 t and 17 t. Burning of household garbage is also common in other Pacific Island countries with emissions creating a significant health hazard.[Thaman et al., 2003].

Both the groups (living in the mining community and living in the non-mining community) in this study are located in sugarcane farming areas in the district of Ba, Tavua and Rakiraki. Ba and Rakiraki, where children of the non-exposed group reside, have a sugar mill each but are situated more than 10 km away from the three nursing zones. The Tavua district, where Vatukoula is located, does not have a sugar mill. Both Ba and Rakiraki have more sugar cane farms than Tavua. The sugarcane production for Ba and Rakiraki for the years 2012, 2013, 2014 in tonnage were 325 115, 360 996, 434 337 vs 177 832, 159 720, 171 274, while Tavua had lower tonnage of 140 205, 137 830, and 161 893 tonnes.[?] Burning of sugarcane before harvesting is a common practice in Fiji. The Fiji Sugar Corporation estimated that over 95% of all sugar cane burning is deliberate while the rest of 5% are due to lightning, carelessness or neighbourly sabotage (davies1998causes). Studies have pointed out the significant increase in sugarcane burning since the 1960s (davies1998causes, reddy2003farm). Both studies have highlighted sugarcane burning as a national issue that requires intervention due to its wide impacts ranging from soil fertility, sugar production, economic, environmental and health issues. It is likely that the smoke generated from the burning of sugarcane can be a nuisance and a source of health problems. Due to the higher number of sugarcane farms in Ba and Rakiraki, children residing near farms in these two districts are likely to be more exposed to sugarcane burning

smoke during the cane harvesting season than those living in Tavua where Vatukoula Gold Mine is also located. A study conducted in Araraquara in the state of São Paulo, Brazil, found a significant and dose-dependent relationship between the number of hospital visits for inhalation therapy due to acute respiratory distress and the amount of sediments (the amount of particles deposited on four containers filled with water) from sugar cane plantation burning. The result showed that burning of sugarcane plantation is likely to affect the respiratory health of those exposed [Arbex et al., 2000]. It is also possible that some of the emissions from the two sugar mills may reach communities where non-mining region children reside, but at shallow concentration due to dispersion and dilution likely to occur along the way. The risk of sugar mill emissions reaching these areas is likely to depend on wind direction and velocity. A study conducted in Kushtia Sugar Mill, Bangladesh, found PM10 as the significant air pollutant emitted and having a high concentration in the adjacent surrounding Jagati area of the mill [Tasnuva et al., 2014]. The combined effects of sugarcane burning and sugar mill discharge in the two district are likely to have an impact on the respiratory health of residents. These three factors (indiscriminate burning of household refuse, burning of sugarcane farms and sugar mill emissions) may provide the possible explanation for the high prevalence of acute upper respiratory infections in the non-gold mining group.

The map (Figure 5.1 below shows the locations of the study sites (Vatukoula, Nailaga, Balevuto, Vunitogoloa), the health facilities (Tavua Health Center (for Vatukoula children), Nailaga Health Center, Balevuto Health Center, Vunitogoloa Nursing Station) where data were collected and the two sugar mills (Rarawai Sugar Mill in Ba (closer to Nailaga and Balevuto) and Penang Sugar Mill in Rakiraki (closer to Vunitogoloa).

Indo-Fijian children ($p < 0.01$); female children ($p = 0.84$); children of low birth weight ($p = 0.69$); while the proportion for those children not exclusively breastfed and those exclusively breastfed were similar ($p = 0.99$).

Living in gold mining region and pneumonia

This study found that living in the gold mining region was the single statistically significant risk factor for pneumonia. Air pollution generated from gold mining activities is the likely contributor to this effect. Air pollution, particularly from sulfur dioxide and dust, were always the cause of concern to the Vatukoula Gold Mine residential communities. The effect of sulfur dioxide on respiratory health are known and documented. Sulphur dioxide emission is still a major air pollutant of concern amongst the Vatukoula residential communities [Ackley, 2008]. Studies have documented the presence of sulfur as a nuisance since the early days of the mine in the 1930s [Emberson-Bain, 2002]. The residents of Vatukoula mentioned sulfur dioxide during the focus group discussion; and was also highlighted during the key informant interview by MO-VGM, SEO-MRD, SEO-DOE and Vatukoula Zone Nurse. The zone nurse indicated respiratory illnesses as one of the leading health issues in Vatukoula. The MO-VGM highlighted a severe breach of the control and management of sulphur dioxide emission in Vatukoula made known by the EO-VGM. The stack in the mine has reached its capacity and is unable to filter air pollutants. Therefore, the residential communities within the vicinity of the mine are likely to be exposed to high levels of sulfur dioxide. A typical example is the Nasomo case in mid-2017 where mothers and their babies were rushed to the hospital for treatment due to what the community termed as "lutu na sulphur" meaning "fallout of sulfur". The lack of reliable air quality data makes the matter worse as no one has any idea of the level of sulfur dioxide that the residents of Vatukoula are inhaling. Children may be exposed to more sulphur dioxide than adults because they breathe

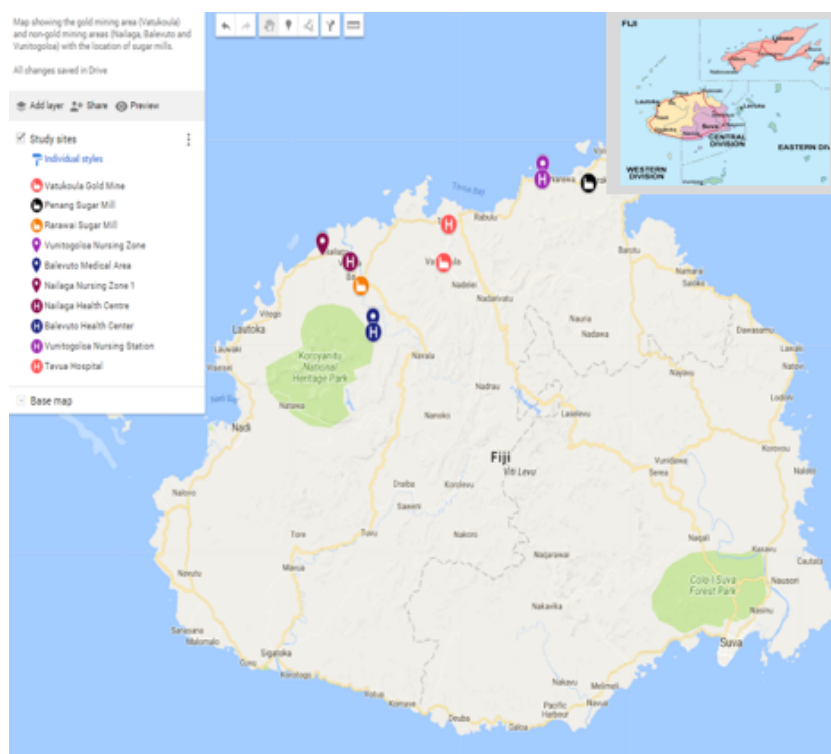


Figure 5.1: Map showing locations of study sites located in the western part of Fiji islands towards the northwest of the main island of Viti Levu.

more air for their body weights than adults do[ATSDR, 1998].

Short-term exposure to sulfur dioxide is likely to affect the human respiratory system and make breathing difficult[EPA, 2017g]. Exposure to SO₂ leads to respiratory symptoms in people with underlying pulmonary disease and also in healthy patients[Chen et al., 2007]. The role of SO₂ in contributing to the high prevalence of pneumonia in the mining region in this study can be attributed by the property of this harmful pollutant in the atmosphere. The emission of high concentration of sulfur dioxide in the air contribute to the formation of other sulfur oxides (SO_x)[EPA, 2017g]. These SO_x will then react with other compounds in the atmosphere to form small particles. These small particles contribute to particulate matter (PM) pollution which are small enough to penetrate deep into the sensitive parts of the lungs and cause severe health problems[EPA, 2017g]. Pneumonia is the disease of the lungs while AURI is the disease of the upper respiratory tract. The exposure of children to PM affects their lung development, that include reversible deficits in lung function, chronically reduced lung function in addition to chronically reduced lung growth rate and reduction in long-term lung function[World health Organization, 2017]. Exposure to air pollution increases the incidence of acute lower respiratory infection critically affecting the nonspecific host defenses like filtration, mucociliary and more, and affects specific host defenses like cellular and humoral immunity[Smith et al., 2000].

Exposure to sulphur dioxide and suspended sulphates for three years or longer was an essential factor that increased the risk of acute respiratory infection in the US[French et al., 1973]. Exces-

sive acute respiratory diseases were associated with communities heavily polluted with sulphur dioxide and suspended sulphates [French et al., 1973]. The Vatukoula Zone Nurse indicated that the number of respiratory infections in children in Vatukoula was high as compared to her previous workstation (Tarau, personal communication, December 13, 2017). She also added that acute viral infections was the most infection for all ages in her zone. The participants of focus group discussion noted an increase in respiratory tract infection, eye infection and skin infection immediately after the category five Cyclone Winston that struck Fiji. They suspected that these might be due to the strong wind dispersing dust from leaves, rooftops and other surfaces and coming into contact with individuals. The exposure level was likely to be high during this period as the Vatukoula Gold Mine treatment plant continued its operation despite there were no trees or vegetation to act as buffer to trap air pollutants. Despite all these, the nurse also noticed that respiratory infection has always been neglected or taken lightly by most community members.

Respiratory infections and diarrhoea were the most common health problems in Vatukoula. Skin diseases and eye infection for children were also common for children. The respiratory infections are likely related to gold mining activities. The emissions from the mine's roaster stack which has been emitting air pollutants for the past decade is likely to cause of a widespread respiratory problem in Vatukoula over the years (Carmin et al, 2011). The community relation officer of VGM confirmed that dust and sulphur dioxide were the two common cause of complaints from the residents of Vatukoula. A study by Ackley conducted in 2007 found that 80% of all Vatukoula residents who were interviewed felt that air pollution has harmed their health, and 60% of all interviewed experienced severe respiratory symptoms at approximately one month before the study. The impact of air pollution, especially sulphur dioxide emission, is severely felt by nearby schools located within the Vatukoula mining lease during the operation of Vatukoula Treatment Plant. Personal communication between Ackley and the head teacher of Vatukoula Public School revealed that teachers were forced to close their classroom doors and windows from the beginning of class at 8 a.m. until the early afternoon to minimise their exposure to emissions [Ackley, 2008]. These environmental concerns had also forced teachers to request for transfer to other schools outside Vatukoula [Ackley, 2008]. People living near tailing dams in Vatukoula is also a health concern as some live few meters away from the dam. Wastes produced from mineral processing were stored in tailing dams and expected to hold a high level of pollutants including heavy metals. Harmful air pollutants and dust generated from the tailing dams were likely to affect respiratory health. The WHO estimated that approximately 20% of all deaths of children under five years are due to ARIs (pneumonia, bronchitis and bronchiolitis), where pneumonia accounts for 90% of all these deaths. Management approach in reducing sulfur dioxide and improving air quality in the gold mining region will not only reduce the risk of pneumonia for children but have far more positive impacts on the respiratory health of the Vatukoula population.

Respiratory illness is one of the main health outcomes of concern in gold mining communities around the world. Respiratory infection from mining communities in Obuasi, Ghana, was the result of air pollution emanating from the emission of dust and other chemicals into the air [Selvaraj et al., 2014, Yeboah, 2011, Agyemang-Duah et al., 2016]. It was among the top three diseases directly related to gold mining [Yeboah, 2011]. Health officials who were interviewed in this study also related ARI to air pollution. Acute respiratory infection was a health problem caused by mining as related by participants (70%) of a cross-sectional survey within four communities near the Newmont Ghana Gold Limited, Asutifi District, Ghana. A four-year assessment of the outpatient disease records in this district confirmed with the participant feedback that upper respiratory tract infection (URTI) was also second to malaria in the list of top ten diseases within the district. The risk of acute respiratory infections were almost 41- and 12-fold higher in two gold mining communities (Trakwa Nsuaem Municipality/Prestea-Huni Valley District)

as compared to a non-mining community (Cape Coast Metropolis), Ghana [Armah et al., 2012]. The outpatient and inpatient ARI cases correspond with the high level of heavy metals present in the blood of adult and children, which was due to inhalation of toxic fumes in the two gold mining communities [Armah et al., 2012]. A study in Northern Chile in proximity to the mining industry and respiratory diseases indicated that the risk of respiratory diseases considerably increases closer to gold mine [Herrera et al., 2016].

4.2 Breastfeeding status with AURI and pneumonia

Both the results from the AURI and pneumonia group showed that the prevalence of AURI and pneumonia were lightly more for children who were not exclusively breastfed and those with unknown breastfeeding status, but were both statistically not significant. The survival analysis also painted the same picture, but was also statistically not significant. The description of the AURI group showed more breastfeeding children living in the non-gold mining region (66.13% vs 33.87, $p < 0.01$) which also had very high rate of AURI, while the pneumonia group had more breastfeeding children in the gold mining region (56% vs 43.93%, $p < 0.05$) which had high pneumonia cases. However, the result of this study was not what is usually expected, as exclusive breastfeeding has been proven to be a protective factor for childhood illnesses. The WHO stated that of all the preventative interventions, exclusive breastfeeding has the single most substantial potential impact on child mortality [World Health Organization, 2018b]. In a study of pneumonia hospitalised children in Rwanda, breastfeeding was associated with a 50% reduction in case fatality [Lepage et al., 1981]. A marked decrease in the occurrence of respiratory disease was noticed in breastfed children in an urban community in Canada [Chandra, 1979]. The effect of breastfeeding against pneumonia and AURI in children in Fiji will need further investigation. The Ministry of Health Fiji continues to encourage mothers to practice exclusive breastfeeding as one most important way to protect a child, even though there are several factors. Staff Nurse Akata of Vunitogoloa Nursing Station indicated from her experience that the practice of breastfeeding is reducing while bottle feeding is increasing. Some of the factors affecting breastfeeding that she mentioned include “financial well-being of families, mothers’ education level, and mothers’ commitment to other household chores leaving them with less or no time to breastfeed their children” (Akata, personal communication, November 10, 2017). The reduction in exclusive breastfeeding is also a worldwide challenge. The WHO reported that despite the great importance of breastfeeding to child growth and development, the actual practice of exclusive breastfeeding globally is low, where only 38% of infants aged 0 to 6 months are exclusively breastfed [World Health Organization, 2018b].

4.3 Race with AURI and pneumonia

In this study, the proportion of Indo-Fijians having AURI was significantly high ($p < 0.001$), and they also had significantly lower AURI-free survival rates at the end of first five years of life as indicated by the Kaplan-Meier estimator ($p < 0.05$). This finding can be attributed to the non-mining region being dominated by the Indo-Fijian population who are mainly sugarcane farmers. There are more sugarcane farmers and farms with more production in both Ba and Rakiraki, which are the non-mining region in this study, as compared to Tavua district where the mining region is located [Sugarcane Growers Council, 2014]. Burning of sugarcane farms for harvesting is a common practice in sugarcane growing areas, i.e., both Ba and Rakiraki. Indiscriminate burning is not allowed in the mining region, while anyone can burn anything in the non-mining

region. The two districts in the non-mining region had a sugar mill each while the mining region did not. Being the predominant race in the non-mining region and also being exposed to the above sources of air pollution are the likely explanations for higher AURI amongst the Indo-Fijian children in this study. Past studies conducted in Fiji found Indo-Fijian children had higher admission rates for asthma and also commonly have higher bronchial hyper-responsiveness as compared to I-taukei [Flynn, 1994]. A study on rural children in Fiji found more Indo-Fijian (8.9%) children having higher wheezing rates (four or more episodes of wheeze in a 12 month period) than Fijian (I-taukei) children (2.9%) [Flynn, 1994].

More I-taukei suffer from pneumonia in the first five years of life ($p = 0.77$), and also generally had slightly lower pneumonia-free rates during this period ($p = 0.99$). Even though these results are not statistically significant, past studies in Fiji have indicated the risk of pneumonia to be high for I-taukei children. Magree et al. (2005) in their study on children less than five years to find the incidence and document the clinical features of chest X-ray- (CXR-) confirmed pneumonia found that the rate of presenting with lower respiratory tract infection as 2.5 times higher for Melanesian Fijians (I-taukei), and higher likelihood (29 times) of presenting with CXR-confirmed pneumonia [Magree et al., 2005]. Flynn (1994), in a cross-sectional study of rural children, found more productive coughs on most mornings on Fijian (I-taukei) (35.8%) than Indo-Fijians (23.9%) [Flynn, 1994]. A study by Russel et al., (2006) found that from all the nasopharyngeal (NP) swabs positive with *S. pneumoniae*, Fijian (I-taukei) children had higher carriage rate than Indo-Fijian (RR:2.4), indicating that being indigenous Fijian as an independent risk factor for pneumococcal NP carriage [Russell et al., 2006]. The burden of respiratory infections on indigenous population was also noted in Fiji's neighbouring countries, New Zealand and Australia [Grant et al., 2001, Chang et al., 2009].

4.4 Gender and acute respiratory tract infection

In this study, the proportion of males and females having AURI were similar ($p = 0.84$). At the end of first five years of life, males had slightly lower AURI-free survival rates as indicated by the Kaplan-Meier estimator, but was not significant. A similar finding was noted in a community-based study in rural Delhi where the incidence of upper respiratory tract infections among males and females children under five years was similar [Chhabra et al., 1993].

In the pneumonia group, more males suffered pneumonia ($p = 0.14$), and males also had a lower pneumonia-free survival rate at the end of the five years compared to females ($p = 0.11$), but both were not significant. However, several studies have identified male children having higher risk of ARI than female children [Marbury et al., 1996, Dharmage et al., 1996, Leeder et al., 1976, Ramani et al., 2016, Chhabra et al., 1993, Monto et al., 1974, Bashour et al., 1994]. A longitudinal cohort study conducted on 400 children in Gulbarga to assess the morbidity pattern and determinants of ARI found a significantly higher susceptibility to ARI of boys than girls (OR = 2.41 : 0.41) [Ramani et al., 2016]. The likely reason highlighted by this study could be that boys spend more time outdoors than girls thereby increasing their risk of exposure. In a study of respiratory illness for residents of Tecumseh, Mich, America, males experienced more illnesses than females for children under three years (monto1974acute). A community-based study in Syria on the epidemiology of ARI in children under five years also found male having higher incidence and prevalence of ARI (bashour1994community).

The prevalence of pneumonia was more in males than females in this study. Similar findings were noted in past studies. In a cohort study of more than 2000 children in a residential suburb of north-west London, the incidence of pneumonia was higher for male as compared to

female[Leeder et al., 1976]. The incidence of lower respiratory tract infection was significantly greater in boys in a community-based study on prevalence and incidence of ARI among children under five years in a rural village in Delhi[Chhabra et al., 1993]. Male sex was one of the explanatory variables increasing the risk of acute lower respiratory infection in a case-control study conducted for children under five years in Colombo[Dharmage et al., 1996].

4.5 Birth weight with AURI and pneumonia

In this study, more children with low birth weight had AURI ($p = 0.69$). Also, at the end of first five years of life, this group had lower AURI-free survival rates as indicated by the Kaplan-Meier estimator. The result was the same for the pneumonia group. However, these results were not statistically significant. Other studies have confirmed a significant association between low birth weight and ARI (both AURI and pneumonia). Low birth weight is a significant risk factor associated with increasing number of ARI episodes.[Mitra, 2001]. Infants with low birth weight had a higher incidence of hospital admissions due to pneumonia and bronchitis.[Harlap and Davies, 1974]. A multivariable analysis of explanatory variables for ALRI in children under five years in a case-control study in Colombo found low birth weight as one of the factors that increase the risk of ALRI[Dharmage et al., 1996]. A systematic review of 19 studies that investigated 19 risk factors of acute lower respiratory tract infection found lower birth weight (OR 3.18, 95%CI: 1.02 - 9.90) as one of the seven risk factors that were significantly associated with severe acute lower respiratory tract infection.[Jackson et al., 2013]. The World Health Organization indicated that birth weight together with malnutrition are two relatively common risk factors for pneumonia in developing countries.[WHO, 1991].

4.6 Effectiveness of air pollution management and control in Vatukoula Gold Mine

The effectiveness of air pollution management and control programs by VGM are described in detail in section 2 of Chapter 4. The two sections provide an answer to the second overall objective of this study. The chapter also describes the programs undertaken by the various government departments and their effectiveness in addressing air quality in Fiji, while the MoHMS provided some insights into the effectiveness of childhood health program. Areas needing improvement and those that need to be implemented from the findings of the key informant interviews and the focus group discussion are listed as recommendations in those two sections of Chapter 4. The experiences faced by the Vatukoula community members (section 2 of Chapter 4) that were highlighted in the focus group discussion gives reflect the level of commitment from the management of the mine to address air quality issues. Two main air pollutants, sulfur dioxide and dust have existed since the 1930s, and has continued to put unnecessary concern and fear among the residents of Vatukoula.

In summary, air pollution management and control activities by the management of Vatukoula Gold Mine are yet to meet the standards required to adequately sustain the environment and health of those living within its proximity. The unresolved air pollution issues of sulphur dioxide and dust at Vatukoula over the last eight decades are yet to be resolved. Those who have legal authority over the operation of the mine have done little to resolve these outstanding air pollution issues. The health of those residing near Vatukoula Gold Mine continues to be at risk from the effects of air pollution, as highlighted by previous studies, as well as this study

5 Generalisability of results

The findings from this study are unique in two ways. First is the prevalence of acute upper respiratory tract infection for children under five years living in an- gold mining region. The three nursing zones in the non-mining regions are all located in the rural areas of Ba and Ra and dominated by sugarcane farming. Similar nursing zones throughout three provinces in the western division (Nadroga Province, Ba Province, and Ra Province), and few nursing zones in the Macuata Province in the northern division of Fiji are located in sugarcane farming communities and comprised mainly of the Indo-Fijian population who are mostly sugarcane farmers. The sources of air pollution in these rural nursing zones are similar, with sugarcane farm burning and indiscriminate burning of household refuse as main ones. These provinces share almost the same weather patterns and are the drier parts of Fiji's two main islands (Viti Levu and Vanua Levu). Considering the similarities between the nursing zones in the non-mining region in this study and other similar nursing zones around the western division and northern division, it is likely that the prevalence of acute upper respiratory infection in these nursing zones will also be similar.

Second is the prevalence of pneumonia in children under five years in the gold mining region. The Vatukoula Gold Mine is unique in that it is one of the few gold mines around the world that have residential communities located within its mining lease and very close to the mine. This was the set up from the colonial days. While the house size remained the same, the population in each household has increased over the years, with overcrowding as a problem indicated by the zone nurse for Vatukoula. Vatukoula Gold Mine is the only active gold mine in Fiji while other prospects are coming up. Therefore, the result of this study on the effect of gold mining on ARI cannot be generalised locally, but likely possible for other gold mines globally that have similar set up as Vatukoula.

Chapter 6

Conclusion and recommendation

1 Summary of findings

The assessment of prevalence and survival rates of acute upper respiratory infection (AURI) and pneumonia in this study highlighted two exciting findings; the high prevalence of acute upper respiratory infection in the non-mining region, and the high prevalence of pneumonia (an acute lower respiratory infection) in the gold mining region. The only statistically significant risk factor for AURI was living in non-gold mining region while living in the gold mining region was the only statistically significant risk factor for pneumonia in this study.

The high proportion of AURI in the non-mining region was likely due to the region being exposed to other air pollutants that were not predominant in the gold mining region. In comparison to the gold-mining region, the nursing zones in the non-mining region are surrounded by much more sugarcane farms than the gold-mining region, and data from the Sugar Cane Growers Council indicated the district of Ba and Ra having more sugarcane tonnage production than Tavua. With studies showing the burning of sugarcane as a national issue, it is therefore likely that children born and raised in areas dominated by sugarcane farming are likely to have higher exposure to farm burning fumes than those with less or no sugarcane farms. Indiscriminate burning is a common practice in almost all parts of Fiji, but, residents of Vatukoula will need to get approval from VGM if they want to make an open fire. Indiscriminate burning is another source of air pollution in the non-mining region. The three nursing zones in the non-mining region are located approximately 10 km away from the nearest sugar mill. The likelihood of sugarcane emissions reaching these nursing zones cannot be ruled out, as dispersion will always be subject to wind velocity and wind direction.

The high prevalence of pneumonia in the gold-mining region is likely due to the air pollution generated from the gold mining activities. The issue of air pollution, mainly sulfur dioxide and dust, in the mine has existed for eight decades as according to previous studies and from the responses from the focus group discussion conducted in this study. Air pollution related to gold mining is the highest cause of concern for those residing near the gold mine. The property of sulfur makes it the possible explanation for increased risk of pneumonia in the gold mining region. High concentration of SO₂ in the air contributes to the formation of other sulphur oxides (SO_x). The sulfur oxides (SO_x) formed from the presence of high sulfur dioxide in the atmosphere will react with other compounds in the atmosphere to form small particles, therefore contributing to

particulate matter (PM) which are small enough to penetrate deep into the sensitive parts of the lungs and cause severe health problems. The lack of breastfeeding is likely to predispose children to the effect of air pollution in the gold mining region. Non-exclusive breastfeeding turned out to be a significant risk factor for pneumonia after the multivariate analysis.

Air pollution management and control activities by the management of Vatukoula Gold Mine are yet to meet the standards required to adequately sustain the environment and health of those living in its vicinity. The unresolved air pollution issues of sulphur dioxide and dust at Vatukoula over the last eight decades are yet to be resolved. Those who have legal authority over the operation of the mine have done little to resolve these outstanding air pollution issues. The health of those residing near Vatukoula Gold Mine continue to be at risk from the effects air pollution as highlighted by previous studies, as well as this study.

2 Recommendations and future direction

2.1 Addressing pneumonia risk factors in Vatukoula Gold Mine

Role of VGM management

Living in gold mining region and non-exclusive breastfeeding were the two statistically significant risk factor for pneumonia after crude analysis of pneumonia cases from the gold mining and non-gold mining regions. With the absence of reliable air quality data, the findings from the key informants and the responses from the participants of the focus group discussion brought to light the critical air pollution issues in Vatukoula. Sulphur dioxide and dust were the primary air pollutants highlighted with first-hand testimony of their effects by the participants of focus discussion. The ineffectiveness of the stack, due to its surpassing its lifetime, to filter air pollution, including sulphur dioxide, is a severe breach of the VGM's air quality management plan, policy, and to the local environmental protection laws. However, the VMG is in the right way to addressing harmful air pollutants related to the gold mining activities. It has established an air quality management plan which outlines its plans and targets explicitly. Two of the targets include reducing the nuisance factor of dust and stack emission to the communities, and no regulatory infringement or community concerns arise due to poor air quality/emissions. The AQMP clearly outlines the general emission control measures that need to be taken to achieve the desired targets. It is recommended that VGM seriously and effectively implement these emission control measures to achieve its targets.

In addition to these, improving stack design and maintenance is vital to allow maximum capture of air pollutants, particularly sulfur, and to also allow adequate dispersion of emission. Section 18 (3) of the Environmental Management (Waste Disposal and Recycling) Regulations 2007 requires that the best practicable means should be used to reduce the exhaust of polluting substances from a facility. Proper dispersion at the exhaust of stack is a requirement under Section 18 (a) of this regulation which states "reducing the effects of the exhaust to an acceptable level by dispersion may be necessary in cases where the exhaust concentrations are high. During the interview, the Medical Officer highlighted a report from the EO-VGM that the mineral stack has reached its capacity (lifetime) and is not filtering air pollutants. It is recommended that management of VGM to make sure that this serious breach is attended immediately. The recent case of sulfur dioxide falling at Nasomo and affecting the health of some mother and children raises questions

about the effectiveness of the stack. On the other hand, alternative dust suppressant approach is needed to reduce dust nuisance.

The introduction of standard air quality measurement device by the management of VGM is a positive move towards understanding air quality status in Vatukoula. Apart from other known sources of air pollution in Vatukoula, the participants were concerned about the air quality around the underground mine exhaust systems. This study recommends that these locations be also considered in the air quality management plan.

Turning on of siren before the commencement of operation of the gold processing treatment plant was once a safety practice in Vatukoula Gold Mine but was ceased in the last few years. The warning allowed those living in the vicinity of the mine to remain alert and take precautionary measures. For safety and health reasons, it is recommended that the management reactivate this practice. A schedule of operation times can also be made available to the residents of Vatukoula.

According to the Community Relations Officer of VGM, the company is mindful of the safety and well-being of those residing near the mine, “We are very conscious of them as they are our staffs” (CRO-VGM, personal communication, October 24, 2017). However, this did not correspond with the responses from the participants of the key informant interview who raised their concern about the lack of commitment of the company to effectively resolve pending environmental and health issues. These include the lack of timely feedback to their complaints and the way the communities are left unaware of the risks associated with gold mining. A previous study by Ackley in 2008 recommended for awareness due to the high proportion of participants in that study who were not aware of the risk associated with gold mine and living in fear of the impacts. This study strongly supports Ackley’s recommendation on the importance of creating awareness on gold mining risks as this activity is long overdue. Also, the community complaints about poor air quality needed to be taken seriously and addressed positively by the management. Views and experiences of communities living in the vicinity of the mine should not be undermined but be taken constructively and considered in decision making by the company on issues likely to affect the environment and health.

Participants of the focus group discussion have witnessed the decrease in the number of community visits. Management to improve its communication and engagement with the residents of Vatukoula. Regular communication and engagement between the two parties will build trust and understanding. The company is reminded of its corporate social responsibility towards those that live in its vicinity, and on its mining lease, who are mostly its workers and their families.

Role of government departments

The representatives from the government department that were key informants to this study all stated that they need to do more to ensure that air quality standards are met at Vatukoula. The DOE stressed that it is under-resourced and under-staffed to enforce its regulations effectively. The compliance level from those issued with air pollution permit is low. The MRD stated that in the mining sector, their department’s environment unit focuses more on solid and liquid discharge but not so on emission discharge. The statement from MRD that sulfur dioxide has existed in Vatukoula all over the years without effective intervention should be seriously considered. The MoHMS does not have an established surveillance system with the management of Vatukoula Gold Mine to notify the company directly on diseases arising from the gold mining communities.

Adequate resources and human resources must be allocated the Department of Environment,

now the Ministry of Environment, to facilitate the effective implementation of policies and enforcement of existing regulations addressing air pollution.

Regular communication between MRD, DOE and MoHMS with VGM is necessary for a greater understanding of issues affecting the environment and human health in Vatukoula. It is recommended that the MRD should closely monitor the compliance level of VGM to the mining lease conditions as these conditions are highly likely to affect human health if they are not followed. A permanent solution is required to settle the outstanding sulfur dioxide and dust issues in Vatukoula. Regular communication is also necessary between DOE and VGM on the company's compliance with the air quality management plan. This study recommends that a surveillance system be established between the Tavua Hospital and VGM on diseases arising from the mining region. The VGM management will have to be notified immediately of suspected diseases in the mining region for it to take appropriate action. This has never been the case before as confirmed by the medical officer of VGM and the government zone nurse-in-charge of Vatukoula zone. Considering the nature of gold mining as a noxious trade under the Public Health Act, all public complaints arising from Vatukoula that are relating to the operation of the gold mine must be taken seriously and resolved urgently by authorities concerned. The Tavua Rural Local Authority to regularly consult with DOE and MRD and VGM on health-related matters arising from the mine so that immediate steps are taken to rectify those issues.

The lack of clear classification and reporting of acute respiratory infection in some health facilities, as highlighted by Dr Evelyn, should also be addressed by the Ministry of Health and Medical Services. Further to this, the Senior Information Officer in the MoHMS indicated the need to improve the health information reporting system. Some facilities are yet to connect to PATIS, the on-line reporting system of the ministry. Connecting all facilities to a singular reporting system will standardize the ministry's reporting system and produce reliable data useful for health research and policy development. It is recommended that the MoHMS pursue the improvement and standardizing of reporting of health information.

3 Addressing AURI risk factors in non-gold mining region

The high proportion of children having acute upper respiratory tract infection in the non-mining industry requires further investigation. The likelihood of AURI being related to sugarcane farming activities will need to be confirmed through standard research method. The alarming rate of sugarcane farm burning during the cane harvesting season is of great concern to the health of those that live in these areas. Together with sugarcane farm burning is the common practice of indiscriminate burning of household refuse. Even though there is existing legislation that limits these two activities, the lack of enforcement from authorities is a concern. These pose risks to the respiratory health of those that live in the non-mining region of this study, especially children.

4 Improving child health in Fiji

This study highlighted some challenges in improving child health in Fiji. It is recommended that appropriate planning and action be undertaken to resolve these issues. More awareness of parents on the impacts of their low health-seeking behaviour child health must be a priority child health activity. More research is required in the field of air quality and respiratory health in Fiji, as air pollution has proven to be the single major environmental risk factor for ill health globally.

More evidence-based research is to justify the impact of socio-economic factors on the health of children under five years. Findings from these researchers should be made available locally and to all ministries to facilitate evidence-based policymaking. Health, as defined by WHO, can never be the outcome of MoHMS effort alone but a product of multi-sector successes. Awareness is needed on the proper classification and reporting of ARI in line with the ARI definition from the National Center for Communicable Diseases, Fiji. Connecting PATIS and fully utilising its service in the remaining health facilities which are yet to connect to this system will improve the reliability of health data in Fiji. This is the desire of the Health Information Unit of MoHMS which is vital for effective health research and policy-making.

5 Future direction

This study describes the possible effect of gold mining-related air pollution on child respiratory health in Vatukoula. With the availability of standard air quality monitoring device which should produce reliable data, appropriate research is recommended to identify the causal effect of poor air quality other respiratory infections. The inclusion of school children, as they are most active during this age group; the inclusion of adult to assess for long-term exposure and the inclusion of miner workers are also highly recommended in future research.

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Appendices

Appendix 1: Research Approvals

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2017/76/LR

22 September 2017

Saula Matarawa
School of Health Sciences
UNIVERSITY OF CANTERBURY

Dear Saula

Thank you for submitting your low risk application to the Human Ethics Committee for the research proposal titled "Gold Mining and Acute Respiratory Infection in Children: a Retrospective Cohort Study in Vatukoula, Fiji".

I am pleased to advise that this application has been reviewed and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 19th September 2017.

With best wishes for your project.

Yours sincerely

R. Robinson
pp.

Associate Professor Jane Maidment
Chair, Human Ethics Committee



Figure 6.1: University of Canterbury ethics approval

Appendix 2: Information sheets and consent forms

Appendix 3: Interview and focus group discussion guiding questions

The following are questions that will be used to guide key informant interviews under each key informant:

A. Environment Officer –VGML

1. Describe the type (underground or open cut) and magnitude of gold mining conducted by VGM? Describe their locations?
2. What are the chemicals used by the industry (primarily for gold extraction)? How are they stored? Apart from cyanide, what other chemicals are used during the extraction of gold (e.g., mercury)?
3. Request for process flow chart. Identify the air pollutants likely to be generated from each process.
4. Describe the gold extraction process and identify possible air pollutants in each process. List other air pollution sources in Vatukoula.
5. Is diesel still the energy source for the mining community? What is the daily average volume of diesel used?
6. Request for summary of ore produced, waste generated and if possible, gold produced, over the 5 years. Enter into excel.
7. Describe the typical composition of underground ore for precessing. (e.g., sulphide ore, etc)
8. Typical composition of air pollutants from mine?What are the main air pollution sources within Vatukoula Gold Mine? What are the main pollutants of concern? How are they monitored?
9. Typical composition of slime discharge?
10. Active slime dams within the study period?
11. Have the mine previously had accidental spillage of chemicals, or mine wastes or other similar incidences in the past? If yes, what were the impacts to environment and health? How was it addressed?
12. The raising of Dakovono dam occured in 2015. Describe the process of getting soil to the site. How many truck loads of soil?
13. How does the mine addresses air quality? Does the mine has an "Air Quality Management Plan"? How does the company addresses air quality issues?
14. How is air quality monitored within and around the gold mine?
15. Does the company has a consistent environmental monitoring program, and an EIA? How can you describe the effectiveness of your programs in protecting human health from poor air quality?
16. How do you view air quality as a determinant of health?
17. Do you think the industry's current approach is adequate to protect air quality and health? What are some future plans to protect air quality and health?

18. What are some policies, programs, activities currently in place to protect and promote air quality for good health in the gold mining residential community? How effective are these programs? List the regulations or documents that guide your work.

B. Headteacher

1. What environmental and health concerns do the school has especially being located close to the gold mine?
2. Do you report these concerns to the management? If yes, what was the response from the mine management?
3. How would you describe air quality in the school?
4. Describe the difference in air quality between this school and your previous school?
5. What are the most common illnesses reported by students in your school?
6. A previous study highlighted environmental awareness should be carried out as no program was in place. Has this started?
7. What would you recommend to improve air quality and children health in this area?

D. Community Relations Officer

1. Describe the populations that live close to gold mine?
2. What are the most common complaints received from the residential community?
3. Do you receive air pollution complaints? If yes, how are these air pollution complaints addressed?
4. How does the mine view the health of the residential community as part of the general gold mining community? Does it consider their safety and well-being?
5. Describe the relationship between the industry and the community? Does this relationship assist in solving conflicts within this two groups?
6. How are public knowledge of gold mining air pollution risks addressed?

E. Medical Officer VGML

1. Describe the current health services provided by the clinic? How are community health needs addressed?
2. What are the common sicknesses reported at your clinic? Is respiratory infection one of them?
3. What are the most common sicknesses within the residential community? Is respiratory infections one of them?
4. Is air quality a health concern for the residential community? What is your view on the relationship between air quality and respiratory diseases in Vatukoula?
5. What is the general trend of respiratory illnesses in Vatukoula?
6. Do you raise your findings to the management? If so, what is the response?
7. Is there any partnership between VGM and Tavua Medical subdivision address diseases from the mine residential communities? Discuss.

F. Zone Nurse

1. What are the main health issues affecting children in Vatukoula? Is respiratory illness one of them?
2. As a medical person in close contact with children in this mining community, do you think poor air quality is a threat to children's health? Describe the trend of respiratory illnesses, both those reported and those not reported?
3. What is your view on the relationship between air quality and respiratory infections, especially in children in Vatukoula?
4. How have respiratory infections been addressed in your zone? What else can be done to improve to improve the current situation?
5. How do you compare respiratory infection in children under 5 years in Vatukoula with the medical area that you earlier served in?
6. Are the current programs to address children under 5 years adequate or do we need some improvements? Please discuss.

G. Director Department of Environment

1. How is air quality addressed in Fiji?
2. Does the department conduct its own air quality assessment? How are readings from the waste producers verified, if the department does not do its own readings?
3. How is air quality addressed in the mining industries?
4. How are the industry owners adhering to the regulatory requirements for protection of air quality?
5. Before the enactment of EMA 2005 with its regulation, the Mining Act 1978 was the primary legislation governing mining activities in Fiji. As in Vatukoula Gold Mine, can you describe whether this is still the same or EMA 2005 has taken over? Do those industries existing prior to 2005 also need to submit EIA report?
6. Is MRD still monitoring environmental impacts of mining or has it been taken over by DOE?
7. Apart from EMA and Mining Act, what are there other legislations or policies that guide development and waste management in Fiji, especially in the mining sector?
8. What is your view on the relationship between air quality and human health?
9. One in every nine people globally die from poor air quality. What are the future plan of the department in the protection of air quality as a basic environmental factor and also a major determinant of health?
10. Describe the effectiveness of current programs in protection and promotion of air quality?
11. What are some challenges the department faces in ensuring that air quality are according to standard set?
12. Describe how your role assist in the protection of human health from poor air quality?
13. Check the air quality standard, does it align to the WHO Air Quality Guidelines (AQGs)?

H. Director Mineral Resources

1. No. of mining active mines in Fiji?
2. What is the trend of mining in Fiji?
3. How is air quality been addressed in mining industries?
4. Who else has a say in the issuance of mining license? Apart from the Mining Act, what other documents do you refer to to guide your decision in matters concerning mining, air quality and health?
5. Discuss the compliance level of mines on the Mining Act?
6. As a regulatory agency for mining, what is your view on the relationship between air quality in mines and health?
7. How do you view mining as a contributor to air pollution?
8. What happens if a mine fails to comply with the mining license conditions?
9. How can mining be seen as both an economic and health benefiting industry?
10. How sustainable is the mining business in Fiji, with more emphasis on the protection of the environment and human health?
11. Describe how your role can assist in the protection of human health from poor air quality?

I. National Advisor Environmental Health

1. Acute Respiratory Diseases is the leading notifiable diseases in Fiji. Do you think developments such as mining play a role in this case?
2. How does the department currently address the relationship between air quality and health?
3. Describe the current policies and programs in place within and outside your department to protect human health from poor air quality in Fiji?
4. How easily are recommendations on the protection of human health from poor air quality in all proposed and existing developments taken on board by regulating and approving authorities?
5. What are some future plans in place to protect human health from poor air quality in Fiji?
6. Describe the relationship between the department and the mining industries in terms of protection of human health from poor air quality?
7. Do you think the current systems are adequate to protect the health of our population from poor air quality? If not, what are some ways we can achieve this?
8. Does the department have in place Air Quality Standard in line with the WHO Air Quality Guidelines (AQGs)? Explain and discuss answer.

J. National Advisor Communicable Disease/National Program Manager Acute Respiratory Infections and Diarrhoeal Diseases Control)

1. What is the ARI trend like in Fiji over the years?
2. What are the main risk factors associated with ARI in Fiji?

3. How severe is ARI for children under 5 years in Fiji? (Complications of ARI for children under 5 years)
4. What are some approaches taken to address ARI in Fiji?
5. List some of the available programs (including government policies) to targeting improvement of children under 5 years in Fiji?

FOCUS GROUP DISCUSSION QUESTIONS

The following are guiding questions for the proposed focus group discussion amongst community health workers, the village headman, advisory councilors and Vatukoula Community Concerns Committee:

1. Apart from gold mining, what were other activities that generated a lot of air pollution in the last five years? Describe some of the issues you face during the raising on Dakovono Dam?
2. Current energy source? Most common cooking method? (firewood, gas, etc). Do houses have chimneys?
3. What is the status of air quality in your community over the years? Discuss your experiences on the accumulation of dust on vegetation and other surfaces within and outside your home.
4. What are some common health concerns you have as close residents to the mine?
5. What is your view on the relationship between air quality and health?
6. What are the most common sicknesses experienced in your community? Is respiratory infection one of them?
7. What are the common sicknesses for children? What is the trend of respiratory illnesses for children under 5 over the years?
8. Is air quality in your community ever affected by gold mining? If yes, have you ever complained about it, and what was the response from the time? Has the amount of sulfur pollution decreased in the recent years (report have mentioned the discontinuation of use of elemental sulfur)?
9. Describe the current relationship between gold mine management and communities? How can you compare this with the former management of the mine? Is the monthly Community Visitation Program ongoing? Describe the content of this visitation and how effectively they listen and respond to issues raised? How about risk communication, has it improved after Ackley's study?
10. How can your relationship with the mine be used to address air quality to promote good health?
11. Describe the following: water supply, power supply, cooking methods (type, indoor/outdoor, use of chimney, housing type and quality (condition -good repair, etc), road quality (dust, speeding)

Appendix 4: Mineral deposits in Fiji's two main islands

Appendix 5: Codes used in the analysis

Appendix 5: Fiji's National Air Quality Standard

Table 6.1: Threshold Concentration Table for Ambient Air Quality Standards

Pollutant	Threshold concentration	Permissible excess
<i>Carbon monoxide</i>	10 milligrams per cubic metre	One 8-hour period in a 12-month period expressed as a running 8-hour mean
<i>Nitrogen dioxide</i>	200 micrograms per cubic metre	9 hours in a 12-month
<i>Ozone</i>	150 micrograms per cubic metre	Not to be exceeded at any time
<i>Sulfur dioxide</i>	350 micrograms per cubic metre	9 hours in a 12-month period expressed as a 1-hour mean
	OR 570 micrograms per cubic metre	Not to be exceeded at any time
<i>PM10</i>	50 micrograms per cubic metre	One 24-hour period in a 12-month period expressed as a 24-hour mean

Source: Environmental Management (Waste Disposal and Recycling) Regulations 2007 (Fiji).

Fiji National Health Research and Ethics Review Committee

5th September 2017

Saula Matakara
University of Canterbury,
New Zealand

Project Title: "Gold Mining and Acute Respiratory Infection in Children: A Retrospective Cohort Study in Vatukoula, Fiji".

FNRERC Number: 2017.116.WES.
Primary Investigator(s): Saula Matakara, UC, New Zealand
Principal Supervisor(s): Dr Arindam Basu, UC, New Zealand
Professor Steven Ratuva, UC, New Zealand

Dear Saula,

This is to inform you that the Fiji National Health Research Ethics Review Committee (FNHRERC) has granted scientific, technical and ethical **approval** to your proposal titled "Gold Mining and Acute Respiratory Infection in Children: A Retrospective Cohort Study in Vatukoula, Fiji" on the condition that a copy of the report and data is provided to the Ministry of Health & Medical Services, National Data Repository.

As the Principle Investigator, it is your responsibility to ensure that all the people associated with this particular project are aware of the conditions of this approval and copy of the final report is also submitted to the Ministry of Health and Medical Services at the conclusion of your project for our records.

The following conditions apply to your approval. Failure to abide by these conditions may result in suspension or discontinuation of approval and/or disciplinary action.

1. **Variation to the project:** Any subsequent variation s or modifications you may wish to make to your project must be notified formally to the Chair, FNHRERC for further considerations and approval. If the Chair considers that the proposed changes are significant, you may be required to submit a new application for approval of the revised project.
2. **Incidence or adverse events:** Researchers must report immediately to the Chair FNHRERC anything which may affect the ethical acceptance of the protocol including adverse effects on subjects or unforeseen events that may affect continued ethical acceptability of the project. Failure to do so may result in suspension or cancellation of approval.
3. **Monitoring:** Projects are subject to monitoring at any time by the Committee

Page 1 of 2

Secretariat – Fiji National Health Research Ethics Review Committee, MoHMS, Fiji. 2017

4. **Annual/Final Report:** You must submit a progress report at 6 months of your study and an annual/final report at the end of the year or at the conclusion of the project if it continues for less than or more than a year. Also you are to present the evidence back to the participating institutions.

Please quote the FNHRERC number and the name of the project in any future correspondence.

If you have any further queries or require any additional information, please do not hesitate to contact the Secretariat on telephone: (679) 3306177 ext. 340170 or email: rosimina.tubuitamania@govnet.gov.fj.

We wish you all the best in your study.



Mr. Shivnay Naidu
Chairperson
Fiji National Health Research Ethics Review Committee

**HEALTH INFORMATION UNIT
HEALTH INFORMATION RESEARCH ANALYSIS DIVISION
DATA REQUEST FORM**

MINISTRY OF HEALTH & MEDICAL SERVICES
Shaping Fiji's Health

Pursuant to Health Information Policy 2011, section 3.5, clauses 6 & 12, pg. 9

Please tick the box ☐ yes I agree.

I/We the undersign, agree to submit the final datasets and completed reports to the Health Information Unit & the National Data Repository to the Research Unit within 6-12 months of completion of project or post utilization of this health information. I/We agree that the data is not to be shared with any other requestor without approval from PSHMS for any dissemination of data.

Signature: [Signature] Date: 12/07/17

For Official Use Only

1.0 Data Assessment & Verification

1.1 Snr Statistician Comments/Recommendations: (on availability & accessibility of data)

Data requested is available

Signature: [Signature] Date: 05/08/17

1.2 Health Research Officer Comments/Recommendations: (if requested data is for research purposes)

Hi please provide as this has been approved and approval letter is awaiting FINRENC CHAIRS signature.

Signature: [Signature] Date: 05/09/2017

1.3 Director Epidemiologist Recommendations: (for data quality assessment)

Signature: _____ Date: _____

2.0 Approval

PSHMS Final Decision:

Approved ☒ Not Approved ☐

Signature: [Signature] Date: 6/9/17

3.0 Data Submission (For Health Information Unit Use Only After Approval)

Data Collated by: (Name & Initial) _____ Date: _____

Verified by: (Name & Initial) _____ Date: _____

Submitted by: (Name & Initial) _____ Date: _____

Remarks: _____

Figure 6.3: Ministry of Health Fiji approval for extraction of data

Request letter to Ministry of Health, Fiji



Department: College of Education, Health, and Human Development
Telephone: +679 9121022 Email: saulmatakara@gmail.com
[2nd May 2017]

The Permanent Secretary,
Ministry of Health and Medical Services,
Ministry of Health Headquarters,
Dinem House, 88 Amy Street,
P.O.Box 2223,
Government Building, Suva

Dear Sir,

I, Saula Matakara, a staff of Ministry of Health, Fiji, currently on study leave pursuing Master's in Health Science Environmental Health Endorsement at the University of Canterbury, Christchurch, New Zealand. I am doing a thesis by research for this year and is keen to undertake this research back home, Fiji.

The proposed topic for my research is "Gold mining and acute respiratory disease among children under 5 years at Vatukoula, Fiji". The study seeks to identify whether gold mining has an impact on the incidence of acute respiratory infections (ARI) on children under 5 years in this mining community.

This will be a retrospective cohort study where a non-mining community, Nailaga Medical Area, has been selected as a control group. The subject of this study will involve all those children who were born from these two communities in 2011. The health records of these two birth cohorts will then be observed for incidences of ARI from the date of birth until they reach year 5 in 2016. The two cohorts will then be compared to assess whether gold mining plays a role on the incidence on ARI on the exposed group.

The purpose of this letter is to seek your approval to access, retrieve and use the health records of the two cohorts. The records of the exposed group are with the Tavua Medical Subdivision while those of the non-exposed are with the Nailaga Medical Area, under the Ba Medical Subdivision. I am also seeking your approval for the interview of staffs within the ministry who have an understanding of this topic. These include the Zone Nurse Vatukoula, Sub-divisional Medical Officer Tavua, National Advisor Environmental Health and National Advisor Communicable Diseases.

As a principal researcher in this study, I will abide by the conditions set out by the Ministry of Health Research Ethics committee.

The project is being carried out as a Thesis for Masters in Health Science under the supervision of Dr. Ariandum Basu and Professor Steven Ratuva who can be contacted on following emails: arindam.basu@canterbury.ac.nz and steven.ratuva@canterbury.ac.nz respectively. They will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you have any other queries about this study, please contact me on email saulmatakara@gmail.com or phone 9121022.

Yours sincerely,

.....

Figure 6.4: Ministry of Health Request Letter



Department: College of Education, Health, and Human Development
 Telephone: +679 9121022 Email: saulmatakawawa@gmail.com
 [2nd May 2017]

[Gold Mining and Acute Respiratory Infection in Children: A Retrospective Cohort Study in Vatukoula, Fiji]

Information Sheet for [Vatukoula Gold Mine Limited](#)

I, Saula Matakawawa, a Master's of Health Science student at the University of Canterbury, Christchurch, New Zealand is the principal researcher of the above topic. The purpose of this study is to find out whether gold mining has an impact on the incidence of acute respiratory diseases (ARD) within children under 5 years at Vatukoula. Health records of children from health facilities will provide secondary data while primary data will be collected through key informant interview and focus group discussion. The result from this study will assist in better understanding of the risks of acute respiratory diseases in children under 5 years old in a mining community.

The purpose of this letter is to kindly request your permission on the use of ambient air quality data for assessment of ARD risk as an outcome of this study. I am also requesting your approval for the interview of key informants who are likely to contribute to this study. Few selected key informants include the General Manager, Environment Officer, Medical Officer and Community Relations Officer. Their selection is based on their role and level of awareness and experience on the topic which they may contribute towards this study. If approved, I have prepared separate information sheet and consent form for each participant. The information sheet has in detail information about their conditions of participation.

Participation is voluntary and they have the right to withdraw at any stage without penalty. They may ask for their raw data to be returned to them or destroyed at any point. If they withdraw, I will remove information relating to them. However, once analysis of raw data starts on 24th August 2017, it will become increasingly difficult to remove the influence of their data on the results. The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation. Their identity will not be made public without their prior consent. To ensure anonymity and confidentiality, the researcher will respect their views on how their information and identity should be treated. Only the researcher will have access to your data and also have the responsibility for securely storing them. All data collected will be submitted with the Thesis to the University of Canterbury at the end of the study after which they shall be stored under the university's conditions. The university will discard the data after ten years. However, a thesis is a public document and will be available through the UCLibrary. If you wish to receive a copy of the summary of results of this study, please feel free to indicate it in the consent form attached.

The project is being carried out as a Thesis for Masters in Health Science under the supervision of Dr. Ariandam Basu and Professor Steven Ratuva who can be contacted on following emails: arindam.basu@canterbury.ac.nz and steven.ratuva@canterbury.ac.nz respectively. They will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form and return it through my email, saulmatakawawa@gmail.com

If you have any other queries about this study, please contact me on email saulmatakawawa@gmail.com or phone 9121022.

Figure 6.5: VGML Information Sheet

Department: College of Education, Health, and Human Development
Telephone: +679 9121022 Email: saulmatakawawa@gmail.com
[2nd May 2017]

Gold Mining and Acute Respiratory Infection in Children: A Retrospective Cohort Study in Vatukoula, Fiji

Consent Form for Vatukoula Gold Mine Limited

Please indicate that you have consented to the following by placing a tick (✓) in each of the boxes and signing at space provided underneath.

- ☐ I have been given a full explanation of this project and have had the opportunity to ask questions.
- ☐ I understand what is required from the company if it agrees to take part in the research.
- ☐ I understand that our participation is voluntary and we may withdraw at any time without penalty. Withdrawal of participations will also include the withdrawal of any information we have provided should this remain practically achievable.
- ☐ I understand that any information or opinions we provide will be kept confidential to the researcher and the University of Canterbury and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library.
- ☐ I understand that all data collected for the study will be kept in locked and secure facilities and in password protected electronic form and will be destroyed after ten years.
- ☐ I understand the risks associated with taking part and how they will be managed.
- ☐ I agree to have our contribution recorded
- ☐ I agree for the use of ambient air quality data by the researcher only for the purpose of this study
- ☐ I would like a summary of the results of the project
- ☐ I understand that I can contact the researcher, Saula Matakawawa, on email and phone (saulmatakawawa@gmail.com, 9121022) or his supervisors, Dr. Ariandum Basu and Professor Steven Ratuva on their respective emails, arindam.basu@canterbury.ac.nz and steven.ratuva@canterbury.ac.nz for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☐ By signing below, I have consented to the researcher to enter our facility and also conduct key informant interview related to his study.

Name: _____ Signed: _____ Date: _____

Email address (if you wish to have the result of finding): _____

Figure 6.6: Consent-VGML.PNG

Department: College of Education, Health, and Human Development
 Telephone: +679 9121022 Email: saulmatakawara@gmail.com
 [2nd May 2017]

CHRISTCHURCH NEW ZEALAND

Gold Mining and Acute Respiratory Infection in Children: A Retrospective Cohort Study in Vatukoula, Fiji]

Information Sheet for Key Informant:

I, Saula Matakawara, a Master's of Health Science student at the University of Canterbury, Christchurch, New Zealand is the principal researcher of the above topic. The purpose of this study is to find out whether gold mining has an impact on the incidence of acute respiratory diseases (ARI) within children under 5 years at Vatukoula. Health records of children from health facilities will provide secondary data while primary data will be collected through key informant interview and focus group discussion. The result from this study will assist in better understanding of the risks of acute respiratory diseases in children under 5 years old in a mining community.

The purpose of this letter is to kindly request you to be one of the key informants in this study. Your selection is based on the level of awareness and experience on the topic which you can contribute positively towards this study. I have prepared few questions which will guide us during the interview. Your consent is required if you wish for the interview to be recorded. The interview will last much less than one hour. I am proposing that this interview is undertaken on (date) at (time) at a venue convenient to you.

Participation is voluntary and you have the right to withdraw at any stage without penalty. You may ask for your raw data to be returned to you or destroyed at any point. If you withdraw, I will remove information relating to you. However, once analysis of raw data starts on 24th August 2017, it will become increasingly difficult to remove the influence of your data on the results. The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation. Your identity will not be made public without your prior consent. To ensure anonymity and confidentiality, the researcher will respect your views on how your information and identity shall be treated. Only the researcher will have access to your data and also have the responsibility for securely storing them. All data collected will then be submitted to the University of Canterbury with the Thesis at the end of the study after which they shall be stored under the university's conditions. The university will discard the data after seven years. However, a thesis is a public document and will be available through the UCLibrary. If you wish to receive a copy of the summary of results of this study, please feel free to indicate it in the consent form attached.

The project is carried out as a Thesis for Masters in Health Science by Saula Matakawara under the supervision of Dr. Ariandum Basu and Professor Steven Ratuva who can be contacted on following emails: arindam.basu@canterbury.ac.nz and steven.ratuva@canterbury.ac.nz respectively. They will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form and return it through my email, saulmatakawara@gmail.com

If the proposed interview date and time are inconvenient to you, or if you have any other queries about this study, please contact me on email saulmatakawara@gmail.com or phone 9121022.

Figure 6.7: Key Informant Interview Information Sheet



Department: College of Education, Health, and Human Development
 Telephone: +679 9121022 Email: saulmatarawa@gmail.com
 [2nd May 2017]

Gold Mining and Acute Respiratory Infection in Children: A Retrospective Cohort Study in Vatukoula, Fiji
Consent Form for Key Informant

Please indicate that you have consented on the following by placing a tick (✓) in each of the boxes and signing at space provided underneath.

- ☐ I have been given a full explanation of this project and have had the opportunity to ask questions.
- ☐ I understand what is required of me if I agree to take part in the research.
- ☐ I understand that participation is voluntary and I may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.
- ☐ I understand that any information or opinions I provide will be kept confidential to the researcher and the University of Canterbury and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library.
- ☐ I understand that all data collected for the study will be kept in locked and secure facilities and in password protected electronic form and will be destroyed after seven years.
- ☐ I understand the risks associated with taking part and how they will be managed.
- ☐ I agree to have this interview recorded.
- ☐ I would like a summary of the results of the project
- ☐ I understand that I can contact the researcher, Saula Matarawa, on email and phone (saulmatarawa@gmail.com, 9121022) or his supervisors, Dr. Ariandum Basu and Professor Steven Ratuva on their respective emails, arindam.basu@canterbury.ac.nz and steven.ratuva@canterbury.ac.nz for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☐ By signing below, I agree to participate in this research project.

Name: _____ Signed: _____ Date: _____

Email address (if you wish to have the result of finding): _____

Please send this consent form back to the researcher after signing on email saulmatarawa@gmail.com.

Figure 6.8: Key Informant Consent Form

Department: College of Education, Health, and Human Development
 Telephone: +679 9121022 Email: saulmatarawa@gmail.com
 [2nd May 2017]

UNIVERSITY OF CANTERBURY
 CHRISTCHURCH NEW ZEALAND

**Gold Mining and Acute Respiratory Infection in Children: A Retrospective
 Cohort Study in Vatukoula, Fiji**
Information Sheet for Focus Group Participant.....

I, Saula Matarawa, a Master's of Health Science student at the University of Canterbury, Christchurch, New Zealand is the principal researcher of the above topic. The purpose of this study is to find out whether gold mining has an impact on the incidence of acute respiratory diseases (ARD) within children under 5 years at Vatukoula. Health records of children from health facilities will provide secondary data while primary data will be collected through key informant interview and focus group discussion. The result from this study will assist in better understanding of the risks of acute respiratory diseases in children under 5 years old in a mining community.

The purpose of this letter is to kindly request you to be a participant in a focus group discussion which will be conducted as part of this study. Your selection is based on your role and the level of awareness and experience that you may have on the topic which you may contribute to this study. I have prepared few questions which will guide us during the discussion. Your consent is required for the interview to be recorded. The discussion will last not more than two hours. I am proposing that this focus group discussion is undertaken on (date) at (time) at the Tavua Health Office conference room.

Participation is voluntary and you have the right to withdraw at any stage without penalty. You may ask for your raw data to be returned to you or destroyed at any point. If you withdraw, I will remove information relating to you. However, once analysis of raw data starts on 24th August 2017, it will become increasingly difficult to remove the influence of your data on the results. The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation. Your identity will not be made public without your prior consent. To ensure anonymity and confidentiality, the researcher will respect your views on how your information and identity shall be treated. Only the researcher will have access to your data and also have the responsibility for securely storing them. All data collected will be submitted with the Thesis to the University of Canterbury at the end of the study after which they shall be stored under the university's conditions. The university will discard the data after five to ten years. However, a thesis is a public document and will be available through the UC Library. If you wish to receive a copy of the summary of results of this study, please feel free to indicate it in your consent form attached.

The project is being carried out as a Thesis for Masters in Health Science by Saula Matarawa under the supervision of Dr. Ariandum Basu and Professor Steven Ratuva who can be contacted on following emails: arindam.basu@canterbury.ac.nz and steven.ratuva@canterbury.ac.nz respectively. They will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you have any other queries, please contact me on email, saulmatarawa@gmail.com, or phone, 9121022.

If you agree to participate in the study, you are asked to complete the consent form and return it through my email, saulmatarawa@gmail.com

Figure 6.9: Focus Discussion Information Sheet



Department: College of Education, Health, and Human Development
 Telephone: +679 9121022 Email: saulmatakaraawa@gmail.com
 [2nd May 2017]

Gold Mining and Acute Respiratory Infection in Children: A Retrospective Cohort Study in Vatukoula, Fiji
Consent Form for Focus Group Participant:

Please indicate that you have consented to the following by placing a tick (✓) in each of the boxes and signing at space provided underneath.

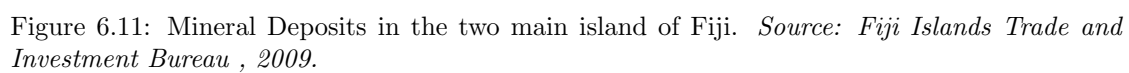
- ☐ I have been given a full explanation of this project and have had the opportunity to ask questions.
- ☐ I understand what is required of me if I agree to take part in the research.
- ☐ I understand that participation is voluntary and I may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.
- ☐ I understand that any information or opinions I provide will be kept confidential to the researcher and the University of Canterbury and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library.
- ☐ I understand that all data collected for the study will be kept in locked and secure facilities and in password protected electronic form and will be destroyed after five to ten years.
- ☐ I understand the risks associated with taking part and how they will be managed.
- ☐ I agree to have my contribution recorded.
- ☐ I would like a summary of the results of the project
- ☐ I understand that I can contact the researcher, Saula Matakaraawa, on email and phone (saulmatakaraawa@gmail.com, 9121022) or his supervisors, Dr. Ariandum Basu and Professor Steven Ratuva on their respective emails, arindam.basu@canterbury.ac.nz and steven.ratuva@canterbury.ac.nz for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☐ By signing below, I agree to participate in this research project.

Name: _____ Signed: _____ Date: _____

Email address (if you wish to have the result of finding): _____

Please send this consent form back to the researcher after signing on email saulmatakaraawa@gmail.com.

Figure 6.10: Focus Group Discussion Consent Form




```
##PNEUMONIA AND BIRTH WEIGHT
pneumonia_tworace$bw1 <- as.factor(pneumonia_tworace$bw1)
pneumonia_tworace$bw2 <- as.numeric(pneumonia_tworace$bw2)
levels(pneumonia_tworace$bw1) <- c("Lowbw1", "Non_Lowbw1")
fit_bw1 <- survfit(surv_prob2 ~ bw1, data = pneumonia_tworace)
fit_bw1
#summary(fit_bw1) this will provide the full summary of the survival data
survbw1 <- survdiff(surv_prob2 ~ bw1, data = pneumonia_tworace)
survbw1
#Austplot(fit_race)
plot(fit_bw1, xlab="Time from birth to first pneumonia (weeks)", ylab="Probability of
pneumonia free survival", main="Kaplan-Meier pneumonia free survival curves by birth
weight status", mark = 3, lwd = 1, lty = 1:2) #3 is to show the censored children; 1:2 is the
line types
legend("topright", c("Low birth weight", "Non_low birth weight"), lty=1:2)
bw1_coxph <- coxph(surv_prob2 ~ bw1, data = pneumonia_tworace)
print(summary(bw1_coxph))

##PNEUMONIA AND EXCLUSIVE BREASTFEEDING
pneumonia_tworace$exbf <- as.factor(pneumonia_tworace$exbf)
levels(pneumonia_tworace$exbf) <- c("Exclusive breastfeeding", "No or unknown
breastfed")
fit_exbf <- survfit(surv_prob2 ~ exbf, data = pneumonia_tworace)
fit_exbf
#summary(fit_exbf) & this will provide the full summary of the survival data
survexbf <- survdiff(surv_prob2 ~ exbf, data = pneumonia_tworace)
survexbf
#plot(fit_exbf, xlab="Time from birth to first pneumonia (weeks)", ylab="Probability of
pneumonia free survival", main="Kaplan-Meier pneumonia free survival curves by
breast feeding status", mark = 3, lwd = 1, lty = 1:2) #3 is to show the censored children;
1:2 is the line types
legend("topright", c("Exclusive breastfeeding", "No or unknown breastfed"), lty=1:2)
exbf_coxph <- coxph(surv_prob2 ~ exbf, data = pneumonia_tworace)
print(summary(exbf_coxph))

#MULTIVARIATE COX REGRESSION
MODEL1 <-
sex_conf <- coxph(surv_prob2 ~ addr + sex, data = pneumonia_tworace)
print(summary(sex_conf))

MODEL2 <-
exbf_conf <- coxph(surv_prob2 ~ addr + exbf, data = pneumonia_tworace)
print(summary(exbf_conf))

ANALYSIS OF ACUTE UPPER RESPIRATORY INFECTION

mydata_auri <- read_csv("auri.csv")
View(mydata_auri)

aui_count <- mydata_auri %>%
  group_by(sex, type) %>%
  summarise(aui_type = n, distinct(aui_type))
print(aui_count)
#Rearrange Severe Pneumonia or Severe Disease with Pneumonia so that I can remove
them in the next command
mydata_auri$auri_type[mydata_auri$auri_type=="Severe Pneumonia or Severe Disease"]
<- "Non-severe"

auri <- mydata_auri %>%
  mutate(time2 = mdy(dmy("%d/%m/%y")), #can also use 'w', 'l' as suggested by Dr. Baou
time1 = mdy(dmy("%d/%m/%y"))
duration = difftime(time2, time1, units = "weeks"))

View(auri)
#Now we create the survival object
survprob_auri <- Surv(auri$duration, auri$auri_type) # the survival object
print(summary(survprob_auri))

survival_diff <- survdiff(survprob_auri ~ auri$addr)
survival_diff
# Use the survfit function to test the association between exposure and survival time
fit_auri <- survfit(survprob_auri ~ addr, data = auri)
fit_auri
#summary(fit_auri) this will provide the full summary of the survival data
# Now we plot the survfit function to graphically examine the survival difference
Austplot(fit_auri)
plot(fit_auri, xlab="Time from birth to first AURI (weeks)", ylab="Probability of AURI
free survival", main="Kaplan-Meier survival curves for AURI, by group", mark = 3, lwd = 1,
lty = 1:2) #3 is to show the censored children; 1:2 is the line types
legend("bottomright", c("Exposed", "Non-exposed"), lty=1:2)

View(auri_tworace)

survprob2 <- Surv(auri_tworace$duration, auri_tworace$auri_type)
print(survprob2)

# Now we can use this surv_prob for other calculations
# Are exposed worse than non-exposed?
fit_surv2 <- survfit(survprob2 ~ addr, data = auri_tworace)
fit_surv2
#summary(fit_surv2) this will provide the full summary of the survival data
survdiff_surv2 <- survdiff(survprob2 ~ addr, data = auri_tworace)
survdiff_surv2
#plot(fit_surv2, xlab="Time from birth to first AURI (weeks)", ylab="Probability of AURI-
free survival", main="Kaplan-Meier AURI-free survival curves by residency status", mark =
3, lwd = 1, lty = 1:2) #3 is to show the censored children; 1:2 is the line types
legend("bottomright", c("Moving region", "Non-moving region"), lty=1:2)
survcough <- coxph(survprob2 ~ addr, data = auri_tworace)
print(summary(survcough))

#AURI AND GENDER
# Do girls have less chance of AURI than boys?
fit_gender2 <- survfit(survprob2 ~ sex, data = auri_tworace)
fit_gender2
#survdiff2 <- survdiff(survprob2 ~ sex, data = auri_tworace)
#survdiff2
#Austplot(fit_gender)
plot(fit_gender2, xlab="Time from birth to first AURI (weeks)", ylab="Probability of
AURI-free survival", main="Kaplan-Meier AURI-free survival curves by gender", mark = 3,
lwd = 1, lty = 1:2) #3 is to show the censored children; 1:2 is the line types
legend("topright", c("Female", "Male"), lty=1:2)
# you see that boys survive less than girls for pneumonia
gender2_coxph <- coxph(survprob2 ~ sex, data = auri_tworace)
# for boys: HR: 1.34 [0.94-1.89]
print(summary(gender2_coxph))

# AURI AND RACE
fit_race2 <- survfit(survprob2 ~ race_rec, data = auri_tworace)
fit_race2
#survdiff2 <- survdiff(survprob2 ~ race_rec, data = auri_tworace)
#survdiff2
#Austplot(fit_race)
plot(fit_race2, xlab="Time from birth to first AURI (weeks)", ylab="Probability of AURI-
free survival", main="Kaplan-Meier AURI-free survival curves by race", mark = 3, lwd = 1,
lty = 1:2) #3 is to show the censored children; 1:2 is the line types
legend("topright", c("African", "Indo-Egypt", "Euro"), lty=1:2)
```

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```
race2_coxph <- coxph(survprob2 ~ race_rec, data = auri_tworace)
print(summary(race2_coxph))

## AURI AND BIRTH WEIGHT

auri_tworace$bw1 <- as.factor(auri_tworace$bw1)
#pneumonia_tworace$bw1 <- as.numeric(pneumonia_tworace$bw1)
levels(auri_tworace$bw1) <- c("Lowbw1", "Non_Lowbw1")
fit_bw1 <- survfit(survprob2 ~ bw1, data = auri_tworace)
fit_bw1
#summary(fit_bw1) this will provide the full summary of the survival data
survbw1 <- survdiff(survprob2 ~ bw1, data = auri_tworace)
survbw1
#plot(fit_bw1, xlab="Time from birth to first AURI (weeks)", ylab="Probability of AURI-
free survival", main="Kaplan-Meier AURI-free survival curves by birth weight status",
mark = 3, lwd = 1, lty = 1:2) #3 is to show the censored children; 1:2 is the line types
legend("topright", c("Low birth weight", "Non-low birth weight"), lty=1:2)
bw1_coxph <- coxph(survprob2 ~ bw1, data = auri_tworace)
print(summary(bw1_coxph))

#AURI AND EXCLUSIVE BREASTFEEDING

auri_tworace$exbf <- as.factor(auri_tworace$exbf)
#pneumonia_tworace$exbf <- as.numeric(pneumonia_tworace$exbf)

levels(auri_tworace$exbf) <- c("Exclusive breastfeeding", "No or unknown breastfed")
fit_exbf <- survfit(survprob2 ~ exbf, data = auri_tworace)
fit_exbf
#summary(fit_exbf) #this will provide the full summary of the survival data
survexbf <- survdiff(survprob2 ~ exbf, data = auri_tworace)
survexbf
#plot(fit_exbf, xlab="Time from birth to first AURI (weeks)", ylab="Probability of AURI-
free survival", main="Kaplan-Meier AURI-free survival curves by breastfeeding status",
mark = 3, lwd = 1, lty = 1:2) #3 is to show the censored children; 1:2 is the line types
legend("topright", c("Exclusive breastfed", "No or unknown breastfed"), lty=1:2)
exbf3_coxph <- coxph(survprob2 ~ exbf, data = auri_tworace)
print(summary(exbf3_coxph))

#MULTIVARIATE COX REGRESSION
#MODEL 1
sex2_conf <- coxph(survprob2 ~ addr + sex, data = auri_tworace)
print(summary(sex2_conf))

#Model 3
#Does race confound the association between exposure and AURI?

race2_conf <- coxph(survprob2 ~ addr + race_rec, data = auri_tworace)
print(race2_conf)
# No, gender does not confound the association between exposure and risk of
pneumonia
# Even after adjusting for the effect of gender, we see that
# exposure to gold mining is a risk factor for pneumonia in the first five years
```

End of document

Figure 6.16: Codes page 5